DOCUMENT RESUME

ED 194 309 SE 032 995

AUTHOR	Strickland, A. W.
TITLE	Secondary School Science and Logical Thinking.
INSTITUTION	Indiana Univ., Bloomington. School of Education.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	80
GRANT	NSF-SER77-20590
NOTE	310p.: Not available in hard copy due to marginal legibility of original document. Module 10 "Suggested Readings" removed due to copyright restrictions.
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Biology: Chemistry: Earth Science; General Science: *Information Dissemination: Inservice Teacher Education: *Logical Thinking: Physics; Science Education: Science Instruction: Science Teachers: Secondary Education: *Secondary School Science: *Teacher Workshops: Workshops

ABSTRACT

The goal of this project was to disseminate materials and information contained in two projects previously funded by the National Science Foundation. "Science Teaching and the Development of Reasoning" (Robert Karplus) and "The Cognitive Analysis Project" (John Renner) were the project materials disseminated in a two-phase effort. The first phase focused on creating sub-centers in four states (Indiana, Ohio, Kentucky, and Illinois), training the directors of these sub-centers, and directing their energies toward secondary school dissemination. Phase two dealt with the task of preparing and completing the dissemination effort to public and private secondary school teachers in the four state area. The project provided aid to secondary school teachers in understanding the reasoning levels of secondary school science students (grades 7-12), using Piagetian stages of logical reasoning. (Author/DS)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED194309

SE 032 995

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Mary L. Charles
of the NSF

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT
NSF FORM 98A

RECEIVED
AAB
MAR 17 1980

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I–PROJECT IDENTIFICATION INFORMATION

1. Institution and Address Indiana University School of Education Bloomington, IN 47405	2. NSF Program IDSE	3. NSF Award Number SER77-20590
	4. Award Period From 9-7-77 To 9-30-79	5. Cumulative Award Amount $24,600

6. Project Title
Secondary School Science and Logical Thinking

PART II–SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The primary focus of this grant was to disseminate the research and development of an NSF grant (SED74-18950) awarded to Robert Karplus entitled, Science Teaching and the Development of Reasoning. In order to successfully achieve this purpose, a group of universities from Indiana, Ohio, Kentucky, and Illinois formed a dissemination network. Indiana University at Bloomington acted as the main center, with six subcenters spread throughout the geographical area to provide the most extensive coverage possible. The following were the goals of the project, set forth at the initial meeting of the subcenter directors:

1) to disseminate information relevant to the project to the 17,121 secondary teachers in the four state area.
2) to conduct at least three workshops (type 1.1 to 3.1) at each of the subcenters (expected number of participants to be not less than 280 persons for all seven centers).
3) to attend state, regional, and national meetings to disseminate information to a minimum of 200 key decision-makers.
4) to assist other areas of the country in establishing similar projects to disseminate the Karplus materials.

sec

The results indicate that all the goals have been achieved. Moreover, numbers 2 and 3 as listed above were exceeded by significant numerical amounts.

PART III–TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (✓)	Approx. Date
a. Abstracts of Theses	X				
b. Publication Citations	X				
c. Data on Scientific Collaborators	X				
d. Information on Inventions	X				
e. Technical Description of Project and Results	▨	X			
f. Other *(specify)*	▨	X			

2. Principal Investigator/Project Director Name *(Typed)* A. W. Strickland	3. Principal Investigator/Project Director Signature	4. Date 1/15/80

NSF Form 98A (5-78) Supersedes All Previous Editions

Form Approved OMB No. [illegible]

TABLE OF CONTENTS

Original Grant. 1

Summary of Project Goals. 25

Details of Goal Attainments 26

Project Materials 33

COVER SHEET
INFORMATION DISSEMINATION FOR SCIENCE EDUCATION
NATIONAL SCIENCE FOUNDATION

1. PROJECT TITLE: Secondary School Science and Logical Thinking.

2. SUBMITTING INSTITUTION: Indiana University Foundation
ADDRESS (including zip code)
School of Education, P.O. Box F, Bloomington, IN 47401

3. NAME AND TITLE OF CHIEF ADMINISTRATIVE OFFICER:
Dr. A. W. Strickland, Assistant-Professor, Science Education

4. GRANT TO (IF DIFFERENT FROM 2 ABOVE):
ADDRESS (including zip code)

5. PROJECT DIRECTOR'S NAME: Dr. A. W. Strickland
SOCIAL SECURITY NUMBER: 264-60-3553
TITLE: Assistant-Professor
BUSINESS ADDRESS (including zip code) School of Education, P. O. Box F,
Bloomington, IN 47401
OFFICE PHONE: area code (812); Number 337-8658
HOME PHONE : area code (812); Number 339-8129

6. PROJECT DESCRIPTORS

A. Target Audience (enter number of participants anticipated), by category and total.

4,680 Superintendents/Principals
920 Subject Matter Specialists
17,162 Secondary Teachers (7-12)
____ Elementary Teachers (K-6)
____ Others (Specify)
TOTAL 22,762

B. Grade level for which the information dissemination activity is proposed, (check as many as appropriate).

☐ K-3 ☐ 4-6 ☒ 7-9 ☒ 10-12 ☐ Other

C. Disciplines Involved in Project (check as many as appropriate)
☒ Biological Science
☒ Physical Science
☐ Social Science
☒ Earth Science
☐ Mathematics
☐ Other

D. Geographic Target Area of Activity Indiana, Illinois, Ohio, Kentucky

7. DURATION OF PROJECT: BEGINNING 10, 1977 AND ENDING 3, 1979

8. TOTAL AMOUNT REQUESTED FROM THE NATIONAL SCIENCE FOUNDATION $ 24,586

9. Signature of Project Director named in 5 above
Authorized Signature for Submitting Institution

10. DATE OF SUBMISSION:

National Science Foundation
PROJECT SUMMARY

Name of Institution Indiana University Foundation School of Education - Bloomington	**Address of Institution (include Branch/Campus & Component)** P.O. Box F Bloomington, IN 47401
Project Director (name and title) A. W. Strickland, Assistant-Professor	**Social Security Number** 264-60-3553
Dates of Project Activities October, 1977 to March, 1979	
Title of Project Secondary School Science and Logical Thinking	

Summary (Limit to 22 Pica or 18 Elite Typewritten Lines)

This proposal is to disseminate the materials and information contained in two projects previously funded by the National Science Foundation. Science Teaching and The Development of Reasoning (Robert Karplus) and the Cognitive Analysis Project (John Renner) are the project materials to be disseminated in a two phase effort. The first phase is focused on creating sub-centers in four states (Indiana, Ohio, Kentucky, and Illinois), training the directors of these sub-centers, and directing their energies toward secondary school dissemination. Phase II deals with the task of preparing and completing the dissemination effort to public and private secondary school teachers in the four state area.

The project seeks to aid secondary school teachers in understanding the reasoning levels of secondary school science students (grades 7 - 12), using Piagetian stages of logical reasoning.

TABLE OF CONTENTS

Project Summary 1

Budget Summary . . . . ~~2~~

Budget . . . . ~~3~~

Budget Explanations. . . . . ~~4~~

Narrative 6

  Rationale. 6
  Related Theory and Research. 7
    Overview of Piagetian Theory 7
    Science Teaching and the Development of Reasoning. 10
    Cognitive Analysis Project 11

  Purpose. 13

  Project Design 13
    Phase I. 14
    Phase II 15
    Project Publicity. .16
    Workshop Format. 18
    Personnel, Facilities, and Management Procedures 20
    Evaluation 22
  References 24

Appendices

A Science Teaching and the Development of Reasoning: Summary of Ideas 25

B Science Teaching and the Development of Reasoning: Workshop Planning and Management Guide 27

C Area Student Population Table 38

D Projects Activities Calendar. 40

E Teacher (Phase II) Workshops. 42

F Vitae: A. W. Strickland. 44

G Vitae: J. Staver 50

H Vitae: M. Cohen. 54

I Letters of Support. 60

NARRATIVE

Rationale

Few, if any, of us have never experienced the blank look of students who have not understood what we had just taught. We are all aware of large differences in students' abilities to understand science concepts, conduct investigations, or solve problems. Some science students are extremely capable, while others demonstrate particular and inappropriate reasoning strategies. Ideas which seem imminently clear to you remain illusive to some students even though seemingly great effort has been generated toward understanding. Often students are able to follow problem solutions but are at a loss when required to transfer those strategies to slightly different problems. You might have some students who can perform well on a certain test, but a month later might have difficulty passing the same test.

Several science educators, with the aid of National Science Foundation Grants, have sought an understanding of these situations and of student differences by examining the developmental theory of Jean Piaget. Science educators such as Robert Karplus, Warren Wollman, Anton Lawson (Lawrence Hall of Science), Arnold Arons (University of Washington, Seattle), Kenneth Lovell (Leeds, England), Eric Lunzer

(Nottingham, England), John W. Renner (Norman, Oklahoma), Michael Shayer (London, England), and Antonio Suarez (Zurich, Switzerland) have all perceived the differences among science students and have explored the work of Piaget for insight in providing more effective instruction.

Related Theory and Research

Overview of Piagetian Theory

Jean Piaget, a Swiss born psychologist, is one of the foremost theorists in child development today. Piaget has formulated a scheme representative of the cognitive intellectual development of the child through a sequence of stages which appear at about the same age in each child. While the order of these periods is fixed for all children, an individual's time-table for entering and leaving each period will vary to some degree. Within each period there are additional levels of cognitive development called stages or substages. A summary of Piaget's (1966) four general stages are as follows:

1) Sensori-Motor Stage - This is the period before the acquisition of language occurring from birth to two years. It is characterized by simple reflexes, beginning habits and elementary means--goals activity. The latter is accomplished by the coordination of vision and the ability to grasp objects and thus alter the immediate situation. The child explores the world from an egocentric point of view.

2) Preoperational Stage - From two to six years the child progressively refines his ability to initiate action subsequent to his observing the situation. Objects and acts are still egocentered; explanations as to "why" are neither inductive nor deductive--the child reasons from the particular. The single most important characteristic of preoperations thought is the inability to mentally reverse a series of actions and realize that a certain series of actions can be "cancelled out" by their inverse series of actions.

3) Concrete Operations Stage - In the period from seven to twelve years the child masters the concept of conservation and can perform logical operations with real objects subject to his manipulation. The concept of number, order (by size and weight), and classification are understood in this stage. The child's thought becomes reversible and he can structure the present in terms of the past.

4) Formal Operations Stage - The final cognitive period is primarily characterized by the ability to reason about logical operations in an abstract fashion (Piaget, 1966). Although Piaget has consistently avoided the association of age ranges with cognitive states, his early work did indicate that adolescents attain the level of fully formal operational thinking somewhere between 11 and 15 years of age.

The latter two stages, the concrete operation stage and the formal operations stage, are relevent to secondary school teachers and students. Students are expected to pass from the concrete operations stage to the formal operations stage during the time they are in the secondary school. Karplus (1974) reported that a great many of the secondary school students do not reach the formal operations stage until much later in life.

Investigators like McKinnon and Renner (1971), and Renner and Lawson (1973) have found that as many as half of the students taking college physical science courses are not operating at the full formal operational stage. Griffiths (1976) and subsequently Kolodiy (1975) found that of the students tested over half of those taking university science courses were not operating at full formal operational stage. Each pointed to the Piagetian process "equilibration" that was lacking from the students' reasoning ability not allowing them to adventure into the formal operational stage.

Prior to the above mentioned studies, Robert Karplus and John W. Renner prepared research grants to more closely examine the formal operations and concrete operations stages. In addition, each sought to communicate the important features of Piaget's theory to secondary school teachers, so that they might apply it in their classroom to help students learn science. In the investigations the area of most concern was the area Piaget called "equilibration":

"Piaget has ascribed the process whereby individuals advance from one stage to the next to four contributing factors: maturation, experience with the physical environment, social transmission, and 'equilibration.'" (Karplus, 1976).

The last of these terms, "equilibration", indicated an internal mental process in which new experiences are combined with prior expectations and generate new logical operations.

It is the analysis of student behaviors operating in the area of "equilibration" which each of the grants has sought to provide new insight into Piagetian stage developments and the evolution of logical reasoning.

Science Teaching and the Development of Reasoning

Robert Karplus, working under a National Science Foundation grant, number SED74-18950, developed the materials referred to as "Science Teaching and the Development of Reasoning." The materials produced by this research grant have resulted in curriculum modules for the secondary school. The modules are designed to examine the transition from concrete operational stage to the formal operational stage in subject areas such as physics, biology, chemistry, earth science, and general science. The basic workshop materials consist of ten modules that involve individual and group activities to introduce teachers to Piagetian ideas and their application to various subject area instructions. The titles of the modules are as follows:

Part I: Reasoning Patterns
1. How students think
2. Concrete and formal reasoning patterns
3. "Formal reasoning patterns"
4. Science texts and reasoning patterns

Part II: Teaching for Self Regulation
- 5. Self-regulation and the learning cycle
- 6. The laboratory and self-regulation
- 7. Concrete and formal concepts
- 8. Tests and self-regulation

Part III: What Can You Do?
- 9. Teaching strategies and goals
- 10. Suggested reading
  Workshop planning and management

A summary of the major ideas of science teaching and the development of reasoning are found in Appendix A. In addition to the main ideas (Appendix A) the focus of this proposal is directed toward the training of teachers in the use of science teaching and the development of reasoning. The Workshop Planning and Management guide for science teaching and the development of reasoning have been included in this proposal (Appendix B).

Cognitive Analysis Project

John W. Renner, under a National Science Foundation grant, number EPP75-19596, developed the materials referred to as "analysis of cognitive processes." The primary purpose of the Cognitive Analysis Project was to find a procedure that could be used to predict the level of intellectual development of a student by analyzing his written language. The project's primary objective was to produce materials that teachers could use with large groups to measure the intellectual development of each member of the group simultaneously.

During the calendar year of 1976 approximately 1,000 students in grades ten through twelve from the public and private schools in Oklahoma were interviewed to determine their levels of intellectual development.

The interviews consisted of having each student respond to four specific tasks which were originally designed by Jean Piaget and Barbel Inhelder. The protocols used to conduct those interviews were first adapted from the work of Piaget and Inhelder by the staff of the Cognitive Analysis Project in January, 1976. Approximately 200 students were interviewed using those protocols. At that point the staff again studied the task protocols and made changes which made the descriptions reflect what was actually done during each interview.

Each task protocol is meant to reflect the criteria Inhelder and Piaget (1958) used in establishing concrete and formal operational subcategories. The ratings assigned to student responses, therefore, are those established by Piaget and Inhelder (Renner, 1977).

The uniqueness of this research was in the establishment of a written test for Piagetian stages and a range which varied from early concrete operational stage (Class IIA) to late formal operational stage (Class IIIB). This test could be useful to the classroom teacher in assessing the logical thought level of students, provided some instructional procedures could be used to aid students in making the transition from one Piagetian stage to the next.

By becoming aware of reasoning patterns needed to understand a particular science course, a teacher can 1) identify the conceptual emphasis and demands of the subject matter and, 2) help students develop more advanced reasoning patterns than they use currently (Karplus, 1976).

Much of what is currently taught in secondary schools involves formal reasoning such as density, temperature, cell, gene, environment, chemical bond, periodic system of elements, acid-base, and momentum. Unless science courses are to become highly selective and admit only students who use formal reasoning patterns with ease, I strongly recommend the formation of formal reasoning patterns be made an important course objective--as important as the covering of a certain body of subject matter.

The material contained in the research grants by Karplus and Renner need to be made available to the classroom teacher; dissemination of these materials could have significant impact on science instruction.

Purpose

The purpose of this proposal is to widely disseminate the materials contained in the National Science Foundation grants awarded to Robert Karplus (Science Teaching and the Development of Reasoning) and John W. Renner (Cognitive Analysis Project). The dissemination of this material should include college science educators, public and private secondary school teachers (grades seven through twelve) in Indiana, Ohio, Kentucky, and Illinois.

Project Design

In the four states selected in this proposal for dissemination of the Science Teaching and the Development of Reasoning, and Cognitive Analysis Project materials there is a total secondary student population of 3,416,157, of which 3,063,558 attend public schools, and the remaining 352,599 attend nonpublic schools (Table 1, Appendix C). In addition, there are approximately 17,121 secondary school teachers in these four states.

To disseminate the science teaching and the Development of Reasoning, and Cognitive Analysis Project materials a Dissemination Design with two phases has been developed.

Phase I

Phase I will disseminate the project information to sub-centers located in each of the four states with emphasis on geographical location. In selecting the sub-centers an effort has been made to involve small colleges with masters degree programs realizing that the college professors at these institutions find it difficult to attend the national meetings where these materials might have been viewed. Furthermore, our investigations have revealed that a significant number of teachers in these four states obtain their masters degrees from many of these small colleges.

The project design has allowed for two sub-centers in Illinois, two sub-centers in Kentucky, three sub-centers in Ohio, and three sub-centers in Indiana (Gary, Indiana will serve the Chicago area.), and the main center at Indiana University, Bloomington, Indiana. The colleges or universities which comprise the center and sub-centers in each state are listed below.

Indiana

Indiana University, Bloomington	Center ✓
Indiana University-Northwest, Gary	Sub-center ✓
Indiana University-Northeast, Fort Wayne	Sub-center
Indiana University-Southeast, New Albany	Sub-center

Illinois

Western Illinois University, Macomb	Sub-center ✓
Southern Illinois University, Carbondale	Sub-center ✓

Ohio

University of Cincinnati, Cincinnati	Sub-center ✓
Case Western Reserve University, Cleveland	Sub-center
University of Toledo, Toledo	Sub-center

Kentucky

University of Kentucky, Lexington	Sub-center ✓
Western Kentucky University, Bowling Green	Sub-center ✓

Each of the sub-center directors will attend a three day conference at Indiana University, Bloomington in the early spring of 1978. Dr. Robert Karplus will be a speaker at this conference, and will aid in the instruction of the workshop for the sub-center directors. The purpose of the conference is to train the sub-center directors using the science teaching and the Development of Reasoning materials, the Cognitive Analysis Project materials, methods and suggestions on teacher dissemination and project evaluation procedures.

Phase II

Phase II will involve the dissemination of the project materials to public and private secondary school teachers. The main vehicle for this dissemination will be workshops on school sites which will represent an inservice effort by the center and sub-centers. These workshops will be designed so that college credit may be issued by the inservice training institution.

Many school systems have expressed an interest in these workshop courses as part of their regular inservice effort. Many teacher centers have expressed an interest in the training of staff in concrete and formal reasoning procedures for use in secondary schools.

In Indiana, two large school systems have already committed themselves for courses using the project materials commencing the summer of 1977. At Indiana University we have developed a sequence of courses which will be offered within Indiana as part of our continuing inservice effort; the demand is more than sufficient to insure the continuation of dessimination of the project materials beyond the scope of this project. I am reasonably confident that the sub-centers' directors will share in this experience.

Project Publicity

The sub-center conference will not need a great deal of publicity since the directors for these centers are part of the project staff and have been selected. In order to communicate the intent and purpose of the project to the 17,121 teachers in the four state area the following methods will be employed:

1) A selected mailing to teachers, principals, and superintendents in the service area of each sub-center (Computer tapes of each of the four states' schools, teachers, principals, and superintendents have already been obtained by Indiana University. Mailing labels will be processed and a bulk mailing to each of these areas will occur during January and February, 1978.).

2) Communication through various State Departments of Education and appropriate staff will be achieved (The project director or assistant-director with the local sub-center directors will meet with state officials in January, 1978.).

3) News releases and short articles will be distributed to state teacher organizations, state science teacher journals, The Science Teacher (a publication of NSTA), and the state principal newsletters.

4) Since three of the states involved have state science teacher meetings which occur in early 1978, plans have been made to conduct workshops at each of these meetings by the project director and/or members of the project staff.

5) At the National Research in Science Teachers meeting in the spring of 1978 the project director and members of the staff will present a paper set on the progress of the dessimination effort. In addition, we will conduct a special workshop for college instructors in the four state project areas.

6) Plans are currently being made to conduct similar workshops at the National Science Teachers Association meeting in the spring of 1978 at Washington, D.C. (These would be special workshops for teachers from the four state area.).

Workshop Format

The Phase I conference will be held on November 10, 11, 12 of 1977 at the Memorial Union on the Indiana University campus in Bloomington. The following is the proposed format:

11/9/77	Arrival of sub-center directors	
11/10/77	8:30 - 9:15 a.m.	Breakfast, Union Cafeteria Annex Speaker: Dr. A. W. Strickland, I. U. (outline of activities and introduction of staff)
	Science Teaching and the Development of Reasoning	
	Session I:	
	9:15 - 9:45 a.m.	Orientation module
	9:45 - 10:20 a.m.	Module 1
	10:20 - 11:00 a.m.	Module 2
	11:00 - 11:30 a.m.	Module 3
	11:30 - 1:00 p.m.	Lunch Break
	Session II:	
	1:00 - 1:40 p.m.	Module 4G (general science)
	1:40 - 2:20 p.m.	Discussion
	2:20 - 2:30 p.m.	Break
	2:30 - 3:10 p.m.	Module 4P (physics)
	3:10 - 3:50 p.m.	Discussion
	3:50 - 4:00 p.m.	Break

4:00 - 4:40 p.m. Module 4C (chemistry)

4:40 - 5:20 p.m. Discussion

5:20 - 7:00 p.m. Break

7:00 - 9:00 p.m. Dinner
Speaker: Dr. Robert Karplus

11/11/77 Session III:

8:30 - 9:10 a.m. Module 4E (earth science)

9:10 - 9:50 a.m. Discussion

9:50 - 10:00 a.m. Break

10:00 - 10:40 a.m. Module 4B (biology)

10:40 - 11:20 a.m. Discussion

11:20 - 12:00 p.m. Module 5

12:00 - 1:00 p.m. Lunch Break

Session IV:

1:00 - 1:30 p.m. Module 5 (continued)

1:30 - 3:30 p.m. Module 6

3:30 - 4:30 p.m. Module 7

4:30 - 6:00 p.m. Break

Session V:

6:00 - 7:30 p.m. Module 8

7:30 - 8:00 p.m. Module 9

11/12/77 Session VI:

8:30 - 10:00 a.m. Module 10 (workshop review augmented by analysis and preparation of additional teaching materials)

10:00 - 10:30 a.m. Break

10:30 - 11:30 a.m. Module 11 (Introduction of the cognitive analysis project materials)

11:30 - 1:00 p.m. Lunch Break

11/12/77 Session VII:

1:00 - 2:30 p.m. Module 12 (use and analysis of Piagetian test instrument created by cognitive analysis project)

2:30 - 2:45 p.m. Break

2:45 - 5:00 p.m. Module 13 (the design of inservice workshops in sub-center areas and methods of evaluation)

5:00 p.m. End of Conference

In addition, the project director will contact all sub-center directors via telephone after the Thanksgiving holiday to ascertain the progress each has made toward designing a local inservice effort. Additional communication will be in accord with the plan of evaluation.

The various workshops which are to be part of Phase II will follow the format suggested in Appendix E. The amount of college credit and number of workshop meetings will vary with institutions. The sub-center directors will have several formats to select from and many options in time scheduling, all of which are covered in Module 13 of the Directors' Conference.

Personnel, Facilities, and Management Procedures

Project Director - Dr. A. W. Strickland (Vitae, Appendix F), Assistant-Professor in Science Education, Indiana University - Bloomington. Dr. Strickland has participated in workshops in Science Teaching and the Development of Reasoning with Dr. Robert Karplus and is very familiar with the Cognitive Analysis

Project materials. His interest and efforts toward inservice of elementary and secondary schools have shown quality, thoroughness, and a willingness to work with fellow teachers. He also has a strong background in Piagetian research.

The Director's responsibilities will be to conduct the business of the dissemination project, organize the sub-center directors conference, to write the final report, and to conduct workshops in Indiana during Phase II.

Assistant Directer - John Staver (Vitae, Appendix G) is a Science Education doctoral student (completed all but dissertation) at Indiana University - Bloomington. Mr. Staver has been very active with the work of Dr. Karplus and has been a staff member at conference workshops using the Science Teaching and the Development of Reasoning materials. Mr. Staver has a strong background in Piagetian studies and is currently completing his dissertation in this area.

His responsibilities will be to assist the Director with the conference and prepare materials for each of the sub-center directors. In addition, Mr. Staver will arrange travel to State Departments of Education, national and state science teachers meetings and aid in collecting data and preparing the final report.

Sub-Center Coordinator - Dr. Michael Cohen (Vitae, Appendix F), Associate-Professor of Science Education, and Chairman of the Science Educationa Department, Indiana University, Bloomington-Indianapolis. Dr. Cohen has a strong interest in the work by Dr. Karplus and Dr. Renner. His efforts in secondary school inservice have been most welcome and worthwhile.

Dr. Cohen's responsibilities will be focused on the coordination of the sub-center directors and working with the project director and other staff members to insure the success of the sub-centers' Phase II efforts. Moreover, he will collect and report the data of the project nationally and locally. His duties will include the participation in preparing the final evaluation report.

Sub-center Directors - The sub-center directors will have the responsibility of preparing themselves, with material supplied by the project director, prior to the directors conference in November, 1977. They will also participate actively in the directors conference and stimulate local administrators to initiate dissemination workshops in their areas. They will develop within their institutions a course offering which will service the needs of the local secondary schools after the completion of the project. Additionally, they will prepare documents for the final evaluation as described in the evaluation section.

Evaluation

The project will conduct the following evaluation procedures to determine if the project goals of dissemination of Science Teaching and the Development of Reasoning and the Cognitive Analysis Project materials:

1) The number of responses from the selected mailing will be reported in the final evaluation.

2) The number of participants at state science teachers workshops will be recorded and reported.

3) The number of participants at the NARST meeting will be recorded and reported.

4) The number of participants at the NSTA meeting will be recorded and reported.

5) A report from each sub-center containing a sequence of activities during the project will be reported. This document will include the following:

a) meeting and efforts to provide inservice workshops,

b) quantity of workshops and numbers of participants and,

c) suggestions on project improvements and further plans at the sub-centers.

6) A selection of articles, reports, newsletters which have been a part of this project will be reported.

References

Griffiths, David. "Physics teaching: does it hinder intellectual development?" American Journal of Physics, 1976, 44, 1:81-86.

Karplus, Robert. "Science teaching and the development of reasoning", Eric Information Analysis Center for Science, Mathematics, and Environmental Education, 1976, ED123128.

Kolodiy, George. "The growth of logical thinking in normal and subnormal children", British Journal of Educational Psychology, 1965, 35:255-258.

McKinnon, J. W. & Renner, J. W. "Are colleges concerned with intellectual development?" American Journal of Physics, 1971, 39:1047-1052.

Piaget, J. "How children form mathematical concepts", Miller, C. A. (Ed.), Frontiers of Psychological Research, San Francisco, CA: W. H. Freeman, 1966.

Piaget, J. & Inhelder, B., The growth of logical thinking. New York: Basic Books, 1958.

Renner, J. W. "Evaluating intellectual development using written responses to selected science problems", A Report to the National Science Foundation on Grant Number EDD75-19596, 1977.

Renner, J. W. & Lawson, A. E. "Formal operations in freshman physics", The Physics Teacher, 1973, 11:273-276.

GOALS OF PROJECT

1. To selectively mail information to teachers, principals, and superintendents within the four state area.
2. To provide a workshop for all the subcenter directors on the training of personnel and the implementation of the project.
3. For each subcenter to provide no less than five workshops on secondary school science and logical thinking (type of workshop [i.e., 1.1 to 3.1] would depend on local environment).
4. To conduct workshops at local, regional, and state science teacher meetings.
5. To aid other states and instructors in preparing grants to disseminate the materials on secondary school science and logical thinking.

PROJECT'S EFFORTS TOWARD MEETING GOALS

1. The first goal was to selectively mail information to teachers, principals, and superintendents within the four states. Our results were as follows:

Indiana:	1) two mailings to all secondary school principals	2,162
	2) one mailing to all superintendents	364
	3) one mailing to all secondary science teachers	3,074
Ohio:	1) six mailings to all secondary science teachers (through a newsletter)	18,474
Kentucky:	1) two mailings to all secondary school principals	1,864
	2) one mailing to secondary school science teachers (members of Kentucky Science Teacher Association)	1,778
Illinois:	1) one mailing to 400 selected science teachers	400
	2) one mailing to 773 science teachers in the Chicago Catholic school system	773

2. To provide a workshop for all the subcenter directors on the training of personnel in the implementation of the project; our results were as follows:

   a) The initial training workshop was held on November 9, 1977. The subcenter directors and nearly fifty additional people attended. The conference and workshop schedule are listed below.

SECONDARY SCHOOL SCIENCE AND LOGICAL THINKING

CONFERENCE AND WORKSHOP

- SCHEDULE -

11/9/77 Arrival of sub-center directors

11/10/77 8:30-9:15 a.m. ** Breakfast, Federal Room, Speaker: Dr. A.W. Strickland, I.U. (outline of activities and introduction of staff)

SCIENCE TEACHING AND THE DEVELOPMENT OF REASONING (Room M40-42)
Session I

9:15-10:00 a.m. ** Module 1

10:00-10:45 a.m. ** Module 2

10:45-11:25 a.m. ** Module 3

11:25-12:00 a.m. ** Module 4

12:00-1:00 p.m. ** Lunch Break

Session II

1:00-1:45 p.m. ** Module 4 (con't.)

1:45-2:45 p.m. ** Module 5

2:45-3:00 p.m. ** Break

3:00-4:30 p.m. ** Module 6

7:00-9:00 p.m ** Dinner, State Room West, Speaker: Dr. Robert Karplus

11/11/77 Session III

8:30-10:00 a.m. ** Module 7

10:00-10:30 a.m. ** Break

10:30-12:00 a.m. ** Robert Karplus, Research Report

12:00-1:00 p.m. ** Lunch Break

Session IV

1:00-2:30 p.m. ** Module 8

2:30-2:45 p.m. ** Break

2:45-3:45 p.m. ** Module 9

3:45-5:00 p.m. ** Sub-center responsibilities: Ways to disseminate information

Session V

7:00-8:30 p.m. ** Sub-center discussion

11/12/77 Session VI

8:30-10:00 a.m. ** Sub-center responsibilities: Reporting and monitoring

10:00-10:30 a.m. ** Break

10:30-12:00 a.m. ** Sub-center responsibilities: Data, evaluation, publications

b) Since our initial meeting, the subcenter directors have met twice to discuss workshop plans and techniques for implementation (April, 1978 and February, 1979).

3. For each subcenter to provide no less than five workshops on secondary school science and logical thinking; results follow:

   a) As can be observed from Table 1 the subcenters held more than the expected 35 workshops. The group conducted 89 workshops within their respective geographical area.

   b) The number of participants far exceeded our expectations and sometimes our planning (several times we ran out of manuals). Table 1 and a description of the workshops are contained in the following pages.

TABLE 1

WORKSHOP TYPES AND NUMBERS OF PARTICIPANTS

Centers	1.1		1.2		2.1		2.2		3.1	
	No. of Workshops	No. of Participants	No. of Workshops	No. of Participants	No. of Workshops	No. of Participants	No. of Workshops	No. of Participants	No. of Workshops	No. of Participants
I.U., Bloomington	4	20	10	177	3	67	7	317	4	34
I.U., Northwest	1	5	1	20	1	10	--	---	--	---
Western Kentucky	2	12	3	105	2	64	2	196	1	7
U. of Kentucky	2	10	4	110	3	60	1	144	1	5
U. of Cincinnati	6	40	3	87	4	71	2	161	1	6
Western Illinois	2	8	1	20	1	13	--	---	--	---
Southern Illinois	6	35	5	116	3	58	2	258	1	6
TOTALS:	23	130	27	635	17	343	14	1076	8	58

WORKSHOPS FOR

SECONDARY SCHOOL SCIENCE AND LOGICAL THINKING

The purpose of this grant is to disseminate information about the Karplus materials entitled "Secondary School Science and Logical Thinking." The National Science Foundation does not expect or permit the training of large numbers of classroom teachers under this particular grant. Therefore, this grant must provide the necessary information to appropriate personnel so that insight may be gained regarding the NSF research project which developed the materials for Secondary School Science and Logical Thinking. To achieve this goal a series of workshops (as prescribed by the project's proposal) have been developed and will be offered to the appropriate audience. The following are the various types of dissemination workshops:

Type 1.1

Objective: to acquaint administrative personnel with the Karplus materials

Audience: science or math coordinators, directors of secondary curricula

Size: range of 1 to 6

Type 1.2

Objective: to acquaint school personnel with the Karplus materials

Audience: secondary school principals and assistant principals

Size: range of 2 to 20

Type 2.1

Objective: to acquaint and train selected science classroom teachers with the Karplus materials

Audience: secondary science department heads, key science teachers (The purpose of this training session is to provide the necessary knowledge base that will allow these teachers to train others.)

Size: range of 10 to 30

Type 2.2

Objective: to acquaint and train selected classroom teachers with the Karplus materials, such that they will be further motivated to explore these materials

Audience: secondary school teachers who are attending a local state or national meeting

Size: range of 20 to 100

Type 3.1

Objective: to acquaint and train selected college science methods instructors in using and providing training sessions for classroom teachers

4. Conduct workshops at local, regional, and state science teacher meetings. This combined effort by the subcenters is as follows:

		Local	Regional	State
Indiana:	I.U., Bloomington	2	4	3
Indiana:	I.U., Northwest	-	-	-
Kentucky:	Western Kentucky U.	3	1	-
Kentucky:	U. of Kentucky	4	1	-
Ohio:	U. of Cincinnati	6	2	-
Illinois:	Western Illinois U.	1	-	-
Illinois:	Southern Illinois U.	3	1	-

5. To aid other states and institutions in preparing grants to disseminate the materials on secondary school science and logical thinking: We have been in correspondence with 13 institutions who have been attempting to gain funding for a similar project. To date three of these have secured funding.

PROJECT MATERIALS

PART I
REASONING PATTERNS

1. How Students Think
2. Concrete and Formal Reasoning Patterns
3. "Formal Reasoning Patterns"
4. Science Texts and Reasoning Patterns

Discussion

MODULE 1
HOW STUDENTS THINK

Introduction

You have probably been curious at various times in your teaching career about the thinking strategies that students use in their science courses. Sometimes it appears that they simply do not reason the way we would. What do many students do when we would employ reasoning patterns such as recognizing the whole to be the sum of its parts, separating variables, or applying mathematical relationships such as ratios? Upon looking more closely at students' responses to certain carefully designed puzzles, you will find that they reflect genuine difficulties in reasoning.

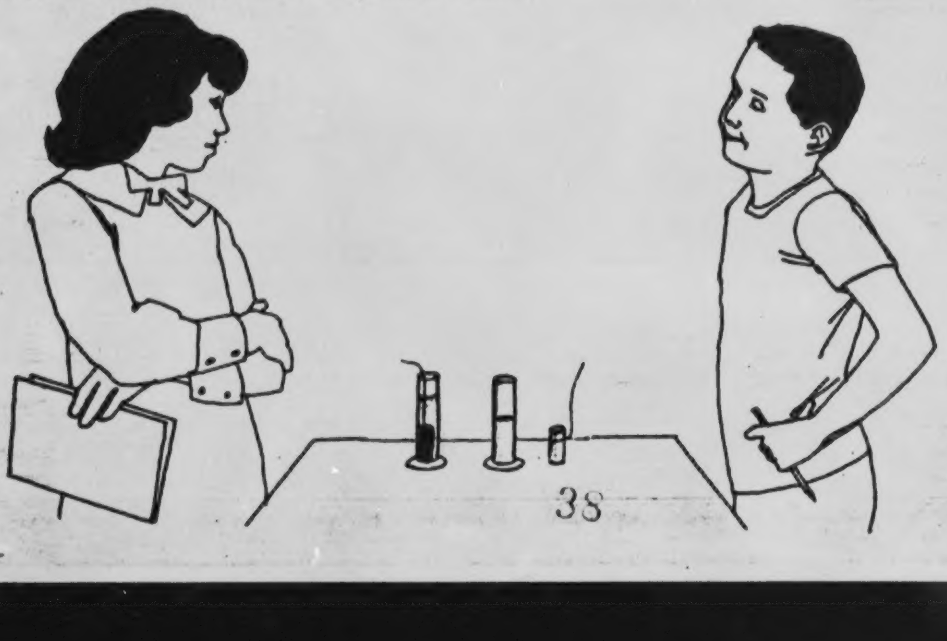
Objective

To assist you in distinguishing among various patterns of thought used to solve simple problems in science.

Procedure

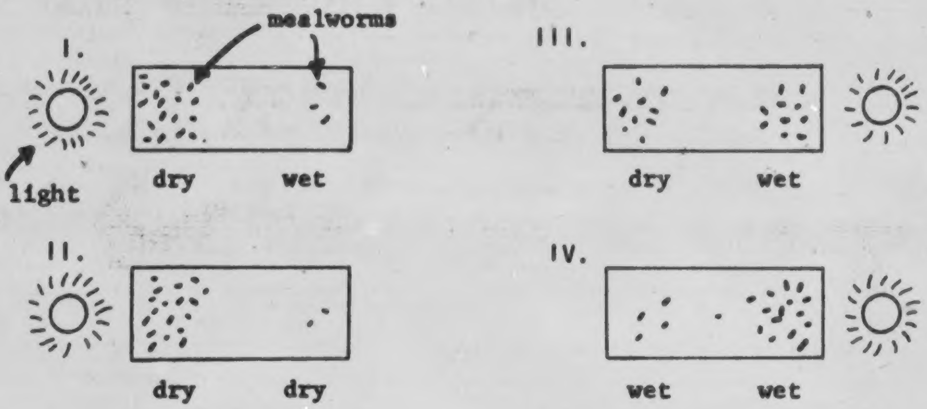
This module includes three puzzles: the Volume Puzzle (page 1-2), the Mealworm Puzzle (page 1-5), and the Ratio Puzzle (page 1-9). Each puzzle is followed by several typical student responses to the puzzle. Please complete at least two of the puzzle activities by writing out your own solution to the puzzle and then comparing your ideas with those of the students. The puzzles may be used in any order. Then please answer the review questions and fill out the Module 1 Evaluation before going on to the next module.

Do not be concerned if you later reconsider the puzzle answers you wrote down, or have difficulty expressing your ideas. Anyone may be misled at first; anyone may grope for an elusive expression and be frustrated when it cannot be pinned down.



THE MEALWORM PUZZLE

An experimenter wanted to test the response of mealworms to light and moisture. To do this he set up four boxes as shown in the diagram below. He used lamps for light sources and constantly watered pieces of paper in the boxes for moisture. In the center of each box he placed 20 mealworms. One day later he returned to count the number of mealworms that had crawled to the different ends of the boxes.



The diagrams show that mealworms respond to (response means move toward or away from):

A) light but not moisture.

B) moisture but not light.

C) both light and moisture.

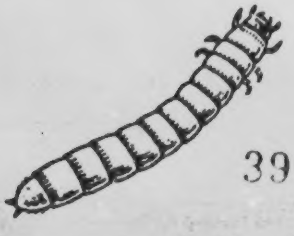
D) neither light nor moisture.

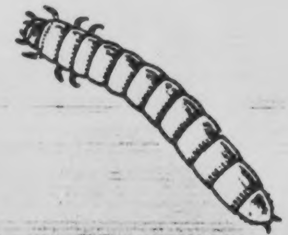
Please explain your choice. ____________________

____

____

____





The following are typical student responses to the Mealworm Puzzle. Read these responses and compare them with your own. Again, look for similarities and differences between type A and type B responses.

Student A_1 (Jerry - Age 15)

D. "No definite pattern was followed by the mealworms."

Student A_2 (Norma - Age 12)

D. "Because even though the light was moved in different places the mealworms didn't do the same things."

Student A_3 (David - Age 14)

A. "They usually went to the end of the box with the light."

Student A_4 (Harold - Age 18)

A. "Because there are 17 worms by the light and there are only 3 by the moisture."

Student A_5 (Mary - Age 14)

A. "Because in all situations, the majority go where there's light. Wetness doesn't seem to make a difference."

Student B_1 (John - Age 16)

C. "Boxes I and II show they prefer dry and light to wet and dark, Box IV eliminates dryness as a factor, so they do respond to light only. Box III shows that wetness cancels the effect of the light, so it seems they prefer dry. (It would be clearer if one of the boxes was wet-dry with no light."

Student B_2 (Roger - Age 15)

C. "When the light was on the dry side they all crowded to the dry side. When it was on the wet side, an equal amount went to each side."

Student B_3 (Dolores - Age 17)

C. "In experiment 3 the mealworms split 1/2 wet, 1/2 dry. So it's safe to assume that light was not the only factor involved."

Student B_4 (Jean - Age 13)

B. "I, II, and III show that mealworms seem to like the light, but in III they seem to be equally spaced. This leads one to believe that mealworms like the dryness and the reason in pictures III and IV they are by the light is because of the heat that the light produces which gives a dryness effect."

Student B_5 (Maria - Age 16)

C. "The mealworms in all cases respond to light. However in box 3 the division is about 1:1. This shows that the worms are attracted to the light but not like the situations where the dry area was next to the light. When there is no choice between wet and dry such as in case IV the worms turn to the light.
Note: We might also test a box like this | wet dry | with no light to further verify the effect of moisture."

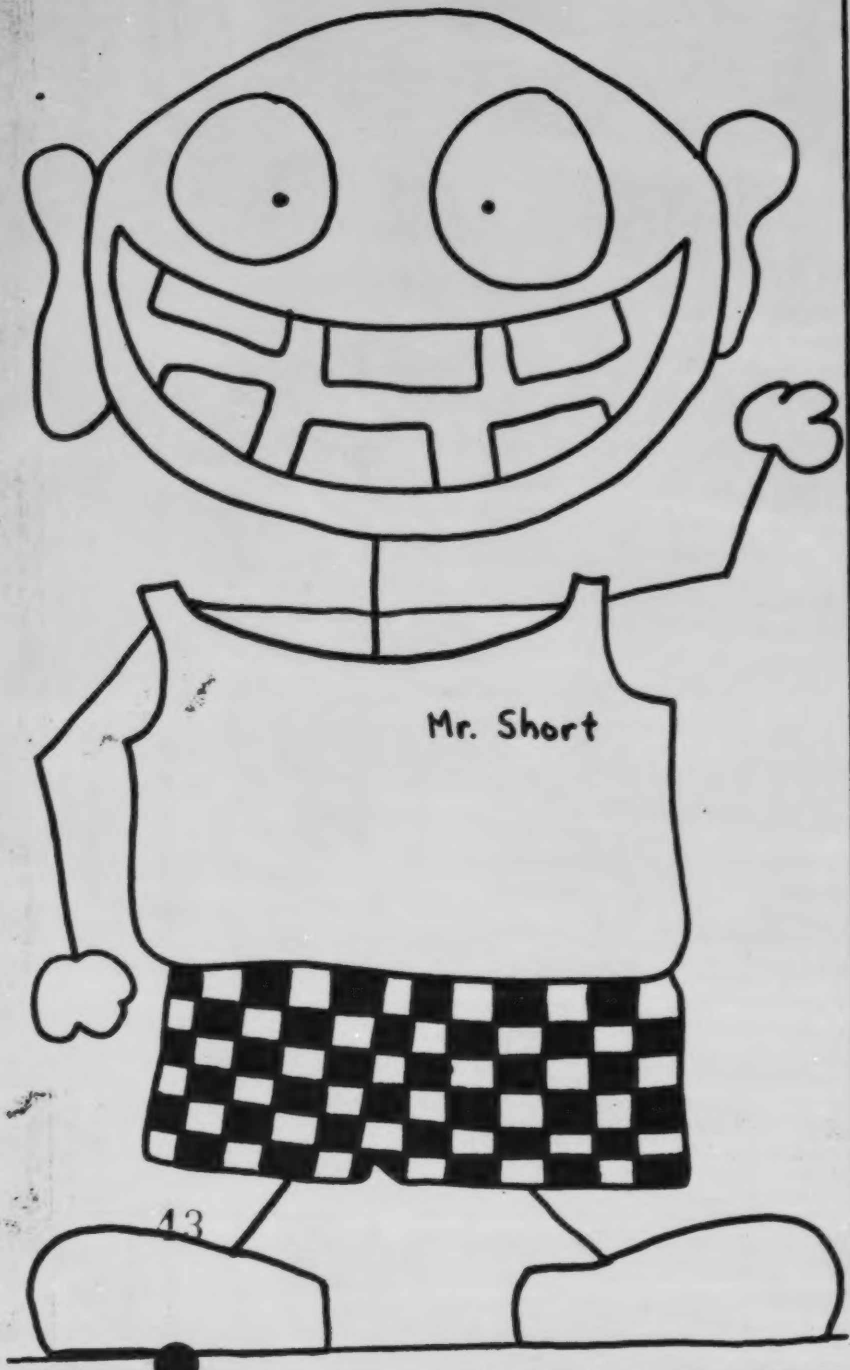
Questions

1. What similarities did you find among the responses of Students A? Please record your analyses here.

2. What similarities did you find among the responses of Students B? Please record your analyses here.

3. What features seem to distinguish type A from type B responses?

Now proceed to another puzzle or to the Review Questions on page 1-14.



THE RATIO PUZZLE

The figure at the left is called Mr. Short. We used large round buttons laid side-by-side to measure Mr. Short's height, starting from the floor between his feet and going to the top of his head. His height was four buttons. Then we took a similar figure called Mr. Tall, and measured it in the same way with the same buttons. Mr. Tall was six buttons high.

Now please do these things:

1. Measure the height of Mr. Short using paper clips in a chain provided. The height is ____
2. Predict the height of Mr. Tall if he were measured with the same paper clips. ________
3. Explain how you figured out your prediction. (You may use diagrams, words, or calculations. Please explain your steps carefully.)

The following are some typical student responses to the Ratio Puzzle. Read them and compare them with your own. Look for similarities and differences between type A and type B responses.

Student A_1 (Henry - Age 14)

Prediction for Mr. Tall: 8-1/2 clips.
Explanation: "If he is 2 buttons taller I guess he is 2 clips bigger which would make it 8-1/2."

Student A_2 (Norma - Age 12)

Prediction for Mr. Tall: 8-1/2 paper clips
Explanation: "Mr. Tall is 8-1/2 paper clips tall because when using buttons as a unit of measure he is 2 units taller. When Mr. Short is measured with paper clips as a unit of measurement he is 6-1/2 paper clips. Therefore, Mr. Tall is 2 units taller in comparison which totals 8-1/2."

Student A_3 (Dolores - Age 17)

Prediction for Mr. Tall: 8 paper clips tall
Explanation: "If Mr. Short measures 4 buttons or 6 paper clips (2 pieces more than buttons), then Mr. Tall should be 2 paper clips more than buttons."

Student A_4 (John - Age 16)

Prediction for Mr. Tall: 9 clips (pencil marks along Mr. Short)
Explanation: "I estimated the middle and then one-fourth of Mr. Short. That's about the size of one button. I measured the button with my clips and found 1-1/2. So then I counted out six times 1-1/2 buttons and got nine."

Student A_5 (Jim - Age 14)

Prediction for Mr. Tall: 12 clips
Explanation: "Mr. Tall was 2 buttons taller than Mr. Short. The buttons must be larger than the paper clips. So I doubled Mr. Short's height in paper clips for Mr. Tall's height."

Student B_1 (Harold - Age 18)

Prediction for Mr. Tall: 9 3/6
Explanation: "Figured it out by seeing that Mr. Tall is half again as tall as Mr. Short, so I took half of Mr. Short's height in clips and added it on to his present height in clips and came up with my prediction."

Student B_2 (Betty - Age 16)

Prediction for Mr. Tall: 9-1/2 paper clips
Explanation: "I figured that the ratio of paper clips to buttons to be approximately 1-1/2 : 1 so two more buttons would make approximately 3 more clips. Since it's a little more than 1-1/2 : 1 he is approximately 9-1/2 clips tall."

Student B_3 (Inez - Age 16)

Prediction for Mr. Tall: 9-1/2 clips
Explanation: "Mr. Tall is 1.5 times the height of Mr. Short, as measured with buttons, and if the measurement techniques were identical would be 1.5 times Mr. Short's height with any measurement medium. Assuming that the measurment techniques are identical, Mr. Tall's height in clips is 1.5 x 6-1/3, which is 9-1/2 (I think)."

Student B_4 (Jean - Age 13)

Prediction for Mr. Tall: 9.2 paperclips.
Explanation: "The ratio using buttons of height of Mr. Short and Mr. Tall is 2 : 3. Figuring out algebraically and solving for x:
$2/3 = \frac{6-1/2}{x}$ gives you 9.2 as the height in paper clips."

Student B_5 (David - Age 14)

Prediction for Mr. Tall: 9 paperclips tall.
Explanation: "I figured out by figuring that Mr. Small is 2/3 as tall as Mr. Tall."

Questions

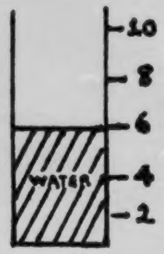
1. Center your attention on several of those responses which were different from yours. See if you can detect any common elements among them. Record those common elements here.

2. Center your attention on those responses which agree with yours and see if you can detect any common elements among the student responses and your response.

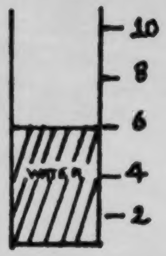
Now proceed to another puzzle or to the review questions on page 1-14.

THE VOLUME PUZZLE

Here are drawings of two vertical tubes (cylinders) which are filled to the same mark with water: the cylinders are identical in size and shape.



Cylinder 1



Cylinder 2

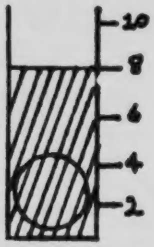
Here are two marbles, one made of steel and one made of glass. Both marbles have the same volume (that is, they are the same size). The steel marble is heavier.

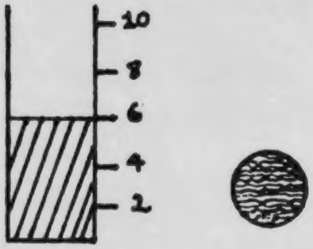
Glass

Steel

The steel marble is heavier than the glass one, but both marbles will sink if placed in one of the cylinders. We are going to put one marble into each of the cylinders.

After we have put the glass marble into cylinder 1, both cylinders and their contents look like this:





If we now put the steel marble into cylinder 2, what will happen to the water level in that cylinder? (Tell whether it will rise, fall, or stay the same; if it rises or falls, tell what the final water level will be in cylinder 2.)

Explain why you predicted the result above:

The next pages present written student responses to the Volume Puzzle. Study the responses and compare Students A with Students B.

Student A_1 (Norma - Age 12)

Prediction: "I think cylinder 2 would be higher to about the number 10 mark."
Explanation: "Because it put more pressure onto the water. This means it would push it upward. The steel ball seems to me like it would be heavier."

Student A_2 (Bob - Age 17)

Prediction: "It will rise. The final water level in cylinder 2 will be 7."
Explanation: "The steel marble is heavier therefore the water will not rise as much."

Student A_3 (David - Age 14)

Prediction: "The level of H_2O in cylinder 2 will rise to higher than 8 - probably 10."
Explanation: "Because the marble in cylinder 2 is heavier than the marble in cylinder 1. It's just like scales, the more weight the higher it goes up."

Student A_4 (Dolores - Age 17)

Prediction: "I think it will stay the same."
Explanation: "I don't really know why. But it would seem the steel marble might have the weight to hold it down. The glass marble is lighter so it pushes the water up."

Student B_1 (Rita - Age 16)

Prediction: "Rise to 8."
Explanation: "Equal volume spheres displace the same volume of water."

Student B_2 (John - Age 16)

Prediction: "The water level in cylinder 2 will rise to the same height as in cylinder 1 after the glass marble is put in."
Explanation: "Both marbles had the same volume, therefore the water level, after the marbles were put in, was the same in each cylinder. The weight in no way affected the degree to which the water rose."

Student B_3 (Jean - Age 13)

Prediction: "Cylinder 2's water level will rise to the number 8."
Explanation: "Since the 2 marbles have the same volume they will displace the same amount of water. Eureka! (weight has nothing to do with it)."

Student B_4 (Harold - Age 18)

Prediction: "The level in cylinder 2 will also be 8; the same as in cylinder 1."
Explanation: "If both marbles are heavy enough to sink and are the same size they will therefore displace the same amount of water thus raising the water level to the same numbers."

Questions

1. What similarities did you find among the responses of Students A? Please record your analysis here.

2. What similarities did you find among the responses of Students B? Please record your analysis here.

3. What features seem to distinguish between the two types of responses?

Now proceed to another puzzle or to the Review Questions on page 1-14.

Review Questions

After you have completed two or three puzzle activities in Module 1, read the following responses and classify them as type A or type B. Compare your answers with those of other participants sitting near you and with ours (bottom of page).

Student X_1 (Age 15) Volume Puzzle

Prediction: Rise above 8 to approximately 10.
Explanation: The weight of the object placed in water displaces an amount of water. Thus if the steel marble was heavier, it displaced more water, causing it to rise above the level of water in which the glass marble was in.

Type _____

Student X_2 (Age 15) Mealworm Puzzle

C. Boxes II and IV have the same moisture conditions on both sides. They show that the mealworms prefer light to darkness. Boxes I and III unfortunately are influenced by both light and moisture factors. Box III has the mealworms equally divided in wet and dry, even though the light is at one end. That means the dry area has an attraction that competes with the light. Box I doesn't really help at all, because there were so few mealworms in the dark end of II that the effect of the additional wetness can't show up.

Type _____

Student X_3 (Age 15) Ratio Puzzle

Prediction for Mr. Tall: 8-1/2 paper clips high
Explanation: "I figured the buttons were the same size as the paper clips. So two more buttons means two more clips for Mr. Tall."

Type _____

Our answers: X_1 - A, X_2 - B, X_3 - A.

MODULE 2
CONCRETE AND FORMAL REASONING PATTERNS

Introduction

You have responded to a few puzzles and have examined responses of students answering these same puzzles. Observations of many children and adolescents attempting to perform similar tasks have led Jean Piaget and other developmental psychologists to formulate theories concerning the mental processes individuals use to deal with problem situations. In this module, we shall introduce you to the idea of patterns of reasoning, a concept that makes it easier to apply Piaget's theory to science teaching. The film included in Module 3 illustrates what we say here.

Objective

To enable you to distinguish between concrete and formal reasoning patterns.

Procedure

Begin by reading the essay, "Classifying Reasoning Patterns" included in the attached instructional materials. Then we ask you to reevaluate the student responses to the puzzles in Module 1 and to participate in a group discussion.

Plan to proceed to Module 3 ("Formal Reasoning Patterns" film) after you have completed these activities. If necessary, interrupt your study of Module 2 to see the film when it is scheduled. If you do make this interruption, complete your work on Module 2 after seeing the film and then proceed directly to Module 4. Note that you should work with a group of colleagues from your subject matter area for Module 4.

Instructional Materials

1. Essay: Classifying Reasoning Patterns

While reading the student responses to the three puzzles in Module 1, you probably recognized that Type B answers were more complete, more consistent, and more systematic than Type A answers. In fact, you may have been somewhat surprised to learn that many secondary school students gave Type A answers!

Each of the answers exemplifies the reasoning of the student who wrote it. You saw substantial similarities among the answers of several students to any one of the tasks. It has also been found that a particular student tends to use a certain approach repeatedly on similar problems. These observations make it useful to introduce the concept of reasoning pattern, an identifiable and reproducible thought process directed at a narrow task. For example, a behavior reflecting use of a reasoning pattern is ordering a set of objects according to an observable property -- arranging several beakers of water in order by how much water they contain.

Jean Piaget created his developmental theory from the relationship and sequence in which he observed subjects of various ages using the reasoning patterns* he had identified. He also introduced the concept of stages of intellectual development. Such a stage is a period when a person's reasoning and behavior show certain distinctive features in terms of the reasoning patterns that are used for problem solving.

Four major stages characterize human intellectual development according to Piaget. All persons progress through the four stages in the same order, though not necessarily at the same rate. The first two, called sensory-motor and preoperational, are usually completed before a child is seven or eight years old. Thus, only the last two are generally applicable to secondary school students; they are called concrete thought and formal thought.

To understand the implications of Piaget's work, one must realize that the stages of development are not as clearly defined or sharply distinguished as the steps of a staircase. Forms of thought of the previous stage are gradually transformed into the new patterns, and a foundation is laid for further advances to the next stage.

In light of the nature of the stages described above, you must not expect most secondary school students to exhibit the reasoning of either the concrete or formal stage exclusively. Rather, a given student may use reasoning appropriate to the concrete stage on some tasks while giving evidence of formal reasoning on quite different problems.

---

*Piaget has identified certain basic reasoning patterns which he has called logical operations. We use the different phrase because we have extended Piaget's notion so as to make it easier for teachers to interpret their students' thinking.

To help you recognize and interpret your students' performance on various thinking tasks, we have assembled examples that will enable you to distinguish between concrete and formal reasoning patterns, appropriate to concrete and formal thought respectively. The use of formal reasoning patterns appears to emerge in the thinking of twelve-year-olds and to increase gradually thereafter if nurtured by appropriate experiences in school and out.

Examples of Concrete Reasoning Patterns

C1 Class Inclusion - classifying and generalizing based on observable properties (e.g., distinguishing consistently between acids and bases according to the color of litmus paper; recognizing that all dogs are animals but that not all animals are dogs).

C2 Conservation - realizing that a quantity remains the same if nothing is added or taken away, though it may appear different (e.g., when all the water in a beaker is poured into an empty graduated cylinder, the amount originally in the beaker is equal to the amount finally in the cylinder).

C3 Serial Ordering - arranging a set of objects according to an observable property and possibly establishing a one-to-one correspondence between two observable sets (e.g., small animals have a fast heart beat while large animals have a slow heart beat).

C4 Reversibility - mentally inverting a sequence of steps to return from the final condition of a certain procedure to its initial condition (after being shown the way to walk from home to school, finding the way home without assistance).

Items C1 through C4 are concrete reasoning patterns. They are applied to concrete objects, directly observable properties, and simple relationships. By using these patterns, the individual can reason and solve problems beyond his or her ability in previous stages. Yet there are many limitations when concrete reasoning patterns are compared to formal ones.

When applying formal thought, an individual reasons without referring to concrete objects or directly observable properties. He or she uses logical and mathematical relationships rather than relying primarily on familiarity and experience. These abilities overcome many limitations of the concrete reasoning patterns mentioned above.

Examples of Formal Reasoning Patterns

F1 Theoretical Reasoning - applying multiple classification, conservation logic, serial ordering, and other reasoning patterns to relationships and properties that are not directly observable (e.g., distinguishing between oxidation and reduction reactions, using the energy conservation principle, arranging lower and higher plants in an evolutionary sequence, making inferences from the theory according to which the earth's crust consists of rigid plates, accepting a hypothesis for the sake of argument).

F2 Combinatorial Reasoning - considering all conceivable combinations of tangible or abstract items (e.g., systematically enumerating the genotypes and phenotypes with respect to characteristics governed by two or more genes).

F3 Functionality and Proportional Reasoning - stating and interpreting functional relationships in mathematical form (e.g., the rate of diffusion of a molecule is inversely propertional to the square root of its molecular weight).

F4 Control of Variables - recognizing the necessity of an experimental design that controls all variables but the one being investigated (e.g., in the Mealworm Puzzle, recognizing the inadequacy of the setup using Box 1).

F5 Probabilistic and Correlational Reasoning - interpreting observations that show unpredictable variability and recognizing relationships among variables in spite of random fluctions that mask them (e.g., in the Mealworm Puzzle, recognizing that a small number of specimen showing exceptional behavior need not invalidate the principal conclusion).

An additional advance in reasoning that is associated with formal thought is the tendency to reflect upon one's own reasoning. By doing so, the individual looks for inconsistencies among conclusions, compares various methods of solving a problem, and checks the appropriateness of a particular theory, model or approximation.

In the following table, we summarize the most important differences between concrete and formal thought:

TABLE 2-1. CONCRETE AND FORMAL THOUGHT

	CONCRETE THOUGHT	FORMAL THOUGHT
(a)	Needs reference to familiar actions, objects- and observable properties	Reason with concepts, indirect relationships and properties, axioms, and theories; recognizes necessary and sufficient conditions for a conclusion
(b)	Uses reasoning patterns C1 - C4, but not patterns F1 - F5	Uses reasoning patterns F1 - F5 as well as C1 - C4
(c)	Needs step-by-step instructions in a lengthy procedure	Plans a lengthy procedure given certain overall goals and resources
(d)	Is not aware of his or her own reasoning, inconsistencies among various statements, or contradictions with other known facts.	Is aware and critical of his or her own reasoning; actively seeks checks on the validity of conclusions by appealing to other known information.

The science teacher who is interested in applying these ideas in his or her teaching should be aware that many theoretical and experimental issues relating to the theory are still being investigated. For instance, Piaget implied that most students develop formal thought -- use formal reasoning patterns reliably -- between twelve and sixteen years of age. Yet recent studies suggest strongly that this does not occur. Since the formal reasoning patterns described above represent extremely worthwhile educational aims, the finding that a large fraction of adolescents and adults do not use them reliably presents a real challenge.

Here are examples of some ways in which the limitations of concrete thought may show themselves in your students' work:

(a) the student identifies some variables influencing a phenomenon, but he or she does so unsystematically;

(b) the student makes observations and draws inferences from them, but does not consider all combinations of experimental conditions and the possible need for more data to support valid conclusions;

(c) the student responds to difficult problems by applying a related but not necessarily correct algorithm, and cannot explain the reason for choosing this procedure,

(d) the student is not spontaneously aware of his or her own reasoning, does not check conclusions against other known data, and does not look for extreme conditions to which a theoretical conclusion could be applied easily for verification.

When classifying reasoning patterns, you sometimes meet examples of student thinking that includes both concrete and formal elements in response to a particular task. This type of reasoning can perhaps best be termed transitional with respect to that and similar tasks.

You must also remember that students may apply memorized formulae, words, or phrases, and appear to be reasoning formally when they are not actually doing so. Probing their conclusions by asking for more details or modifying the conditions of the task usually reveals the depth of their real understanding.

Finally, it may happen that a student can apply a certain reasoning pattern when he or she concentrates on a task, but does not do so when in a hurry or when temporarily distracted. The actual behavior you observe under these conditions will not give a complete indication of the student's ability. Thus, the anxiety and tension often associated with a test may inhibit the formal reasoning being evaluated.

Several research groups are now developing sets of standard tasks on which students may display their reasoning. By using a test of such items, you will be able to identify students who use primarily concrete reasoning patterns, those who frequently use formal reasoning patterns, and those who vary in their approaches on the items. Their performance will give you a general indication of how they are likely to respond to problems and laboratory assignments in your course. By observing the students' performance in your course and keeping in mind the criteria described in this essay, you will be able to assess their level of reasoning directly.

Undoubtedly you are wondering what you can do to help students who use primarily concrete reasoning patterns and are therefore likely to have great difficulty comprehending your course thoroughly. Modules 5 through 9 address this question.

2. Analysis of Student Responses in Module 1

Please re-examine a few student responses to the three puzzles in Module 1. This time, apply ideas from the preceding essay to classify these responses according to the reasoning patterns employed:

PC = Preconcrete (absence of reasoning, as in a guess)
C = Concrete
Tr = Transitional (concrete and limited formal characteristics)
F = Formal
? = not possible to classify without more information

First select one student in Table 2-2. Reread and classify his or her responses to each of the puzzles. Record your classification of reasoning patterns, thus making a "profile" of reasoning for this student. Follow the same procedure for at least two other students -- more if you have time. Then read our analysis of the reasoning involved in each puzzle and our classification of each student's reasoning responses.

TABLE 2-2. RESPONSES OF SIX STUDENTS

Student	(Age)	Puzzle Classification		
		Volume	Mealworm	Ratio
Norma	(12)	____	____	____
Jean	(13)	____	____	____
David	(14)	____	____	____
John	(16)	____	____	____
Dolores	(17)	____	____	____
Harold	(18)	____	____	____

Volume Puzzle

CONCRETE PATTERNS (TYPE A). It is common sense that the weight of an immersed object is responsible for the force that lifts the displaced water. Hence the direct conclusion, given differing weights, is the greater the weight, the higher the water level. (Note that this reasoning leads to the correct conclusion for equal-sized bodies that float!)

FORMAL PATTERNS (TYPE B). Even though the weight is dynamically responsible for lifting the water, the combined volume of water plus marble limits the height to which the water can rise in the container. Since the combined volumes are equal for the two marbles, the water will rise to equal heights if the marbles are fully submerged.

Note the intermediate concept of the combined volume, or the alternate formulation that, if equal marble volumes are added to equal water volumes, the final volumes will be equal. The combined or final volume is not stressed in the statement of the puzzle, but must be introduced by the student.

Mealworm Puzzle

CONCRETE PATTERNS (TYPE A). The student using concrete reasoning patterns concentrates on one variable to the exclusion of others. He cannot detect the logic of the experiment which allows for variables to be isolated and separated so that they can be dealt with as distinct causal agents. He sees the one-to-one correspondences where one factor causes one response in one of the boxes.

FORMAL PATTERNS (TYPE B). Variables are held constant while only one is allowed to change, as in boxes II or IV, or comparing I with III. All possible causal factors are examined in turn to test the hypothesis that light or moisture is responsible for the distribution of the mealworms. The answer will be derived in a systematic manner with each possible conclusion being tested. Probabilistic reasoning is also evidenced by the student's ability to ignore the few mealworms in the "wrong" ends of boxes I, II, and IV.

Ratio Puzzle

CONCRETE PATTERNS (TYPE A). Since the height of Mr. Short measures more paper clips than buttons, students simply add the extra amount to the height of Mr. Tall. Even though the arithmetic difference in units is not stated or asked for, it is a much more direct measure of the qualitative difference than is the ratio, which comes from making a correspondence between each individual button and paper clip.

Another concrete approach makes use of the height difference in buttons of the two figures, and associates that directly with the same difference in paper clips. Note that extra buttons are equated to extra paper clips, in contradiction to the fact that the four buttons measuring Mr. Short are equal to six and not to four paper clips. This inconsistency is not noticed at the stage of concrete thought.

FORMAL PATTERNS (TYPE B). Each button corresponds to a certain number of paper clips, an intermediate quantity not stated in the puzzle nor asked for. Once this conversion ratio is known, the answer is found by simple calculation. Alternatively, the student might conceptualize the height ratio, another intermediate abstraction, and then reason that this ratio must be the same with both units of measurement.

Our Classification

Below is a chart showing the way in which we classified the responses of the six students who attempted all these puzzles in Module 1. Notice that only one student responded consistently to all three puzzles.

Student	(Age)	Puzzle Response Classification		
		Volume	Mealworm	Ratio
Norma	(12)	C	PC	C
Jean	(13)	F	F	F
David	(14)	C	C	Tr or F?
John	(16)	F	Tr or F?	Tr
Dolores	(17)	PC	Tr	C
Harold	(18)	F	C	Tr

Please discuss these results with a workshop staff member and participants at one of the discussion tables. Then complete the Module 2 Review Questions on the next page.

3. Summary

1. Be aware that some of your students use predominantly concrete reasoning patterns.
2. Be aware that many of the science topics you teach require formal reasoning. Identify these topics in advance. (See Module 7)
3. Organize subject matter so it follows a progression from concrete to formal reasoning.
4. Demonstrate to your students a questioning and reflecting attitude towards the science you teach. Generate hypotheses, examine alternative explanations and encourage your students to do the same. Reward this type of behavior in your students for this helps them distinguish hypotheses from facts, reflect upon the meaning of these hypotheses, examine alternative hypotheses, and develop formal patterns of reasoning.

Review Questions

Please write answers to the questions. Then compare your ideas with those of other participants and with our answers below.

1. What are two characteristics of concrete reasoning patterns?

2. What are two characteristics of formal reasoning patterns?

3. How would you classify the answers to the following questions? Explain in each case. "How many different license plates can be made with letters A, B, and C. Describe how you figured it out."

Answer X: Let me see, ABC, CAB, BCA, CBA, BAC, ACB, BCA -- no, I already said that. I guess there are only six, I can't make any more.

Answer Y: It depends on whether you reuse the letters. If you use each one once, you have three choices for the first letter and two for the second and one for the third, three times two times one makes six. If you can have each letter more than once, like in ABB, then you have three choices for each of the three spots, that's three times three times three or twenty-seven. I'd hate to write them all down. There aren't any other possibilities because I took all into account.

Your evaluation of X:

Your evaluation of Y:

Answers:

1. simple classification, serial ordering, one-to-one correspondence, simple causal association, conservation logic.

2. functional relations, hypothetico-deductive reasoning, systematic manipulation and control of variables, reasoning with abstractions.

3. This problem tests combinatorial resaoning and determines whether a student uses concrete trials or a systematic procedure to generate solutions.

   X - concrete; enumerates specific instances, concludes after an error, on the basis of his own inability to produce more possibilities; does not cite a logical limit.

   Y - formal; uses general procedure, considers alternative problem formulations.

MODULE 3
"FORMAL REASONING PATTERNS"

Introduction

In Piaget's theory, concrete reasoning patterns are characterized by serial ordering, simple classification, conservation reasoning, and other operations applied to objects that a person is able to observe or manipulate directly. Formal patterns include these operations but go beyond them to utilize other processes in situations where one does not deal with tangible objects. Formal patterns often involve proportional reasoning, separation of variables, and combinational reasoning.

The film "Formal Reasoning Patterns" (Davidson Films, 1976) will enable you to watch two interviewers working with several secondary school students who exhibit concrete or formal reasoning patterns while responding to four Piagetian tasks. The young people appearing in this film were enrolled in Berkeley's High Potential program for secondary school students. They were above average in showing talent in some area of accomplishment, not necessarily in academic achievement.

The students' performances were completely unrehearsed -- none of them had prepared for the interview or knew in advance what would be required. The scenes in the film were selected to illustrate the concrete and formal reasoning patterns described in Module 2. Though not representative of a random sample of secondary school students, the film demonstrates that a diverse group of such students -- a typical high school class, for instance -- is likely to reveal both types of reasoning patterns.

Objective

To assist you in describing and/or identifying responses that indicate concrete and formal reasoning patterns applied to Piagetian tasks.

Procedure

The film is shown in the Module 3 area. It lasts about thirty-five minutes, but need not be seen in its entirety. Before viewing the film, you may want to familiarize yourself with the four tasks used in the film by looking over the film notes found in the instructional materials. If the film will be shown more than once, you can come back later to view it a second time if you wish.

After completing this module, proceed to Module 4 on Science Textbooks and Reasoning Patterns or complete Module 2. We have not provided review questions for the film.

Film Notes — "Formal Reasoning Patterns"

The interviewers in the film, Drs. Rita Peterson and Robert Karplus, use the probing clinical technique employed by developmental psychologists. They are trying to have the students express their thoughts but not to teach them how to solve the tasks.

The reference for each task contains additional information about the task and the responses of larger numbers of young people.

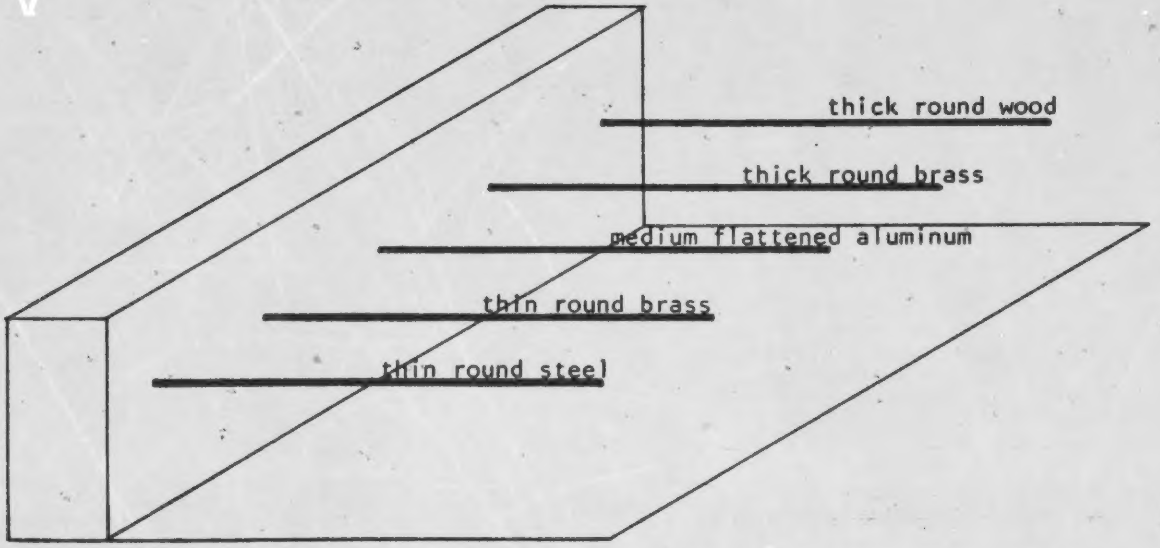
1. Proportional Reasoning (Ratio Puzzle -- Karplus, Karplus, and Wollman. 1974)

The Ratio Puzzle introduced in Module 1 is here used as part of an individual interview rather than as a written assignment for a group of students. The student is shown pictures of Mr. Short and Mr. Tall, and has a chain of large paper clips to measure the height of each. The student is then given a chain of #1 paper clips, measures the height of Mr. Short using these, and finally predicts the height of Mr. Tall measured in "smallies."

The young people in the film illustrate both proportional (formal) reasoning and additive (concrete) reasoning applied to this task.

2. Separation and Control of Variables (Flexible Rods -- Inhelder and Piaget, 1958)

The task shown in the film makes use of a device consisting of five thin rods clamped horizontally. The rods bend when one, two or three washers are attached.



This apparatus permits the adjustment and controlled investigation of four variables: length, thickness, and material of rods; weight or number of washers attached. To verify the effect of length, for instance, the student has to use one rod and a fixed number of washers, and slide the rod in its holder to vary the length. To determine the effect of material, the same number of washers has to be placed on the two thin or two thick rods extended to the same length. The effect of thickness can only be investigated by using the two brass rods, since no other pair is made of the same material.

As you will see in later modules, the formal reasoning pattern of controlling variables is critical for understanding many science experiments and textbook explanations because most natural phenomena depend on several variables. Often this reasoning is taken for granted and inadequate explanations are furnished to students who do not yet apply it.

3. Combinatorial Reasoning (Chemical Mixtures -- Inhelder and Piaget, 1958)

The "coloring liquids" task shown in the film requires the student to identify the role of each of the four liquids combining with a fifth to form a brown color, the color of iodine. The five liquids are:

1 = dilute sulfuric acid
2 = water
3 = hydrogen peroxide solution
4 = sodium thiosulfate solution
G = sodium iodide solution

Liquids 1 and 3 are necessary to form the brown color with G by oxidizing the iodide to iodine. Liquid 2 has no effect -- it may be added or omitted. Liquid 4 prevents the brown color from forming or eliminates it (when present) by reducing the iodine.

The students working on this task illustrate the difference between (1) formal reasoning which goes through the full range of possibilities and (2) the concrete approach of trying combinations unsystematically and incompletely.

4. Application of Proportional Reasoning and Separation of Variables (Equal Arm Balance -- Inhelder and Piaget, 1958)

The last task on the film, balancing the beam, requires students to apply proportional reasoning while separating the variables of weight and distance. There were twenty notches for hanging weights on each side of the fulcrum, with a mark at the tenth notch but no numbering. The weights provided were three, five, seven and ten units made of the same washers as were used in the flexible rods task.

At the beginning of each interview, the student was shown the beam in balance, with ten unit weights at the distance of ten notches on each side of the arm. The following four tasks were then posed:

1. Use a 7-weight and a 3-weight to balance a 10-weight placed ten units from the fulcrum.
2. Use a 5-weight to balance a 10-weight placed at ten units from the fulcrum.
3. Use a 7-weight to balance a 10-weight placed fourteen units from the fulcrum.
4. Use a 7-weight to balance a 5-weight placed at seven units from the fulcrum.

Students using concrete reasoning patterns have a general idea that increased distance on one arm compensates for increased weight on the other arm. They may reason qualitatively or use weight differences rather than ratios in all but the simplest cases of 2:1 comparisons. Formal reasoning patterns are in evidence when the more complicated weight comparisons in items 3 and 4 are treated by ratios.

Concluding Remarks

Our emphasis in this film and in the workshop is on the development of reasoning. Many other factors, such a motivation, interest and anxiety, also influence student performance. Even though we do not discuss these factors in detail, we have kept them in mind. The suggestions for teaching in Part II of this workshop not only enhance reasoning, but may also increase motivation and allay anxiety.

References

"Formal Reasoning Patterns," Davidson Films, 1976.

Inhelder, Barbel and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence, Basic Books, New York, 1958, Chapters 3, 7, and 11.

Karplus, Elizabeth F., Robert Karplus and Warren Wollman, "Intellectual Development Beyond Elementary School IV: Ratio, the Influence of Cognitive Style," School Science and Mathematics, Vol. 75, No. 6, October, 1974, pp. 476-482.

MODULE 4
PHYSICS TEXTS AND REASONING PATTERNS

Introduction

The three preceding modules introduced you to concrete and formal patterns of reasoning. To help you recognize reasoning patterns required when your students read their texts, we have selected excerpts from three physics textbooks for you to read and analyze. Parts of the passages require only concrete reasoning patterns while others require formal patterns. We have made no effort at this point to evaluate any text as a whole and to indicate whether or not the students' preparation for the quoted selection is adequate. The development of physics concepts and its relation to students' reasoning patterns will be taken up in Module 7.

Objective

To assist you in classifying physics text passages in regard to their requirements for concrete and formal reasoning.

Procedure

Choose a partner with whom you will work closely and exchange ideas. Evaluate the demands placed on students' reasoning by the first two excerpts. Compare your views with ours that immediately follow each excerpt. Then read Excerpt 3 and answer the questions concerning it. Discuss your answers with your partner.

Following this, proceed to the designated discussion area for a review of Modules 1-4. At the discussion's conclusion, proceed to Module 5.

Instructional Materials

Excerpt 1. From Project Physics, F. Rutherford, G. Holton, and F. Watson (Directors), Holt, Rinehart, and Winston, New York, 1970, p. 15.

1.4 Leslie's "50" and the meaning of average speed

A

Consider the situation at a swimming meet. At the end of each race, the name of the winner is announced – the swimmer with the shortest time; but since in a given race – say the 100-yard backstroke – every swimmer goes the same distance, the swimmer with the shortest time is the one having the highest average speed while covering the measured distance.

B

The ratio of the distance traveled to the elapsed time is the measure of average speed. This relationship is expressed in the following equation:

$$\text{average speed} = \frac{\text{distance traveled}}{\text{elapsed time}}$$

C

What information does a knowledge of the average speed give us? We shall answer this question by studying a real example.

2.7 ft/sec is the equivalent of 1.8 miles per hour. No great speed! A sailfish can do over 40 mph. But man is a land animal. For short distances he can run better than 20 mph.

Leslie is not the fastest girl freestyle swimmer in the world, but Olympic speed is not necessary for our purposes. One day after school, Leslie was timed while swimming two lengths of the Cambridge High School pool. The pool is 25.0 yards long, and it took her 56.1 seconds to swim the two lengths. Thus her average speed over the whole 50-yard distance was

$$\frac{50.0\text{ yd}}{56.1\text{ sec}} = 0.89\text{ yd/sec, or nearly } 2.7\text{ ft/sec}$$

D

Did Leslie swim the 50 yards at uniform (or constant) speed? If not, which length did she cover more quickly? What was her greatest speed? her least speed? How fast was she moving when she passed the 10-yard, or 18-yard or 45-yard mark? These are useful things to know when training for a meet. But so far we do not have a way to answer any of these questions.

E

The value 0.89 yd/sec probably comes closer than any other *one* value to describing the whole event.

Commentary

This excerpt begins with an easily-visualized situation, a swimming race (A), and the correspondence of shortest time to highest speed for a given distance. Only a concrete reasoning pattern is required to understand this relationship.

The next step involves the definition of average speed in terms of a verbal ratio (B), which is later interpreted numerically. Even though remembering the definition does not require any reasoning, understanding the relationship of the verbal and numerical forms and applying them requires formal reasoning patterns, particularly when the instantaneous speed is clearly not constant.

Note also the question (C), "What information does a knowledge of the average speed give us?" In spite of the promise in the next sentence, the subsequent paragraph does not answer the question -- a real difficulty for a student using primarily concrete reasoning patterns who expects a prompt answer. Further unanswered questions (D) after the brief calculation imply that the average speed concept has very little value. Only at the very end (E) is the significance of average speed described, and this statement makes tacit use of probability, approximation, and models -- definitely formal reasoning patterns and tacitly used at that.

The informed reader who understands average and instantaneous speed realizes that average speed is introduced only as a springboard leading to instantaneous speed -- hence the unanswered questions. Except for the first sentences, however, the excerpt is likely to be very difficult for the beginner, although subsequent paragraphs treat the material via concrete examples which do illustrate some of the general ideas involved. Formal reasoning patterns are required -- this may be inevitable, given the choice of subject matter.

Excerpt 2 From Investigations in Physics, J. Renner and H. Packard, Lyons and Carnahan, Chicago, 1974, p. 286.

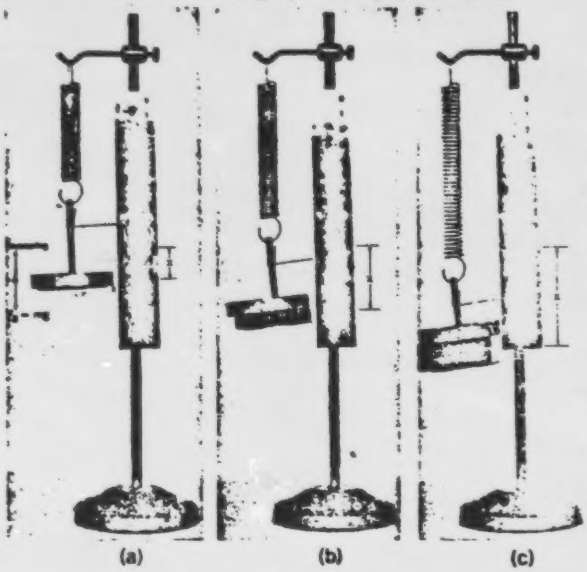


Figure 10.14 Be careful not to stretch a spring too far or you will pull it out of shape and ruin it.

10.4 The vibrating spring

You were successful in showing that the pendulum is a simple harmonic vibrator. A Now let's look at the vibrating spring. What kind of a vibrator is it? Get a spring and some masses and hang the spring from some kind of rigid support. Since the spring hangs down, you can use the force of gravity to stretch the spring. In Figure 10.14 various masses are shown hanging from the spring, stretching it various distances x. Each mass exerts a force on the spring $F_g = mg$ in the downward direction. Or, the restoring force exerted by the spring is B

$$F = -mg.$$

Hang different masses from your spring and make a table of restoring force F and the amount of stretch x. Some actual data are shown in Table 10.3. C

The minus sign in $F = -mg$ shows the direction of F and does not need to be plotted in a graph. Now for your spring plot the magnitude of F as a function of the magnitude of x. Make x the independent variable and put it on the abscissa (the x axis). D What do you conclude about the proportion between F and x from the shape of your graph? E Write the equation for the spring force. From the slope of your graph find the spring constant, k. Your graph may curve a little at the end. This means that when you stretch a spring too far, it will not be a simple harmonic vibrator. You will also ruin your spring. Solution: do not stretch it so far.

You have shown that your spring is a simple harmonic vibrator, and you have an equation for your spring force, F

$$F = -kx.$$

Table 10.3

mass (kg)	weight, F_g(N)	F(N)	stretch, x(m)
0	0	0	0
0.5	4.9	−4.9	0.074
1.0	9.8	−9.8	0.150
1.5	14.7	−14.7	0.223
2.0	19.6	−19.6	0.292

Commentary

This excerpt has the general objective of leading the reader to identify a spring-mass system as a simple harmonic oscillator (vibrator). The passage begins with a reference to a previous related activity (A) which consisted of a seven-step algebraic derivation. This procedure certainly required formal reasoning patterns.

The derivation of the spring's restoring force (B) ostensibly starts from the force F_g exerted by the mass on the spring. Unless the latter fact is memorized, one has to go back another step to the force of gravity acting on the mass when at equilibrium, hence subject to zero net force. This sequence of logical steps requires formal reasoning.

Only concrete level reasoning is needed to follow the instructions for taking data, tabulating them (C), and graphing them (D). Examples of data tables and line graphs were presented earlier as methods for displaying information in an orderly form. Given this data, formal reasoning is required to recognize the proportionality (E), especially in view of the fact that sources of error will make the data deviate slightly from proportionality.

The answer to the initial question is given at the end of the passage (F). Actually, the final equation states Hooke's law for the spring. An extended chain of formal reasoning steps had been used earlier to relate simple harmonic motion and a linear restoring force.

Excerpt 3. From Physics: Principles and Problems, J. Murry and R. Smoot, C.E. Merrill Pub. Co., Columbus, 1972, p. 75.

[illegible]

One method to determine the mass of a body is to use a beam-balance. By this method, an unknown mass is placed on one pan at the end of a beam. The known masses are added to the pan at the other end of the beam until the pans balance. Since the force of gravity then is the same on each pan, the masses must also be the same on each pan. The beam-balance method actually is one of comparison rather than of weighing. A It has the advantage of eliminating all concern about the variations of gravitational force from place to place. The same result for a measurement by the beam-balance method is obtained anywhere. B The mass of a body when measured by comparison with known masses on a beam-balance is called the gravitational mass of the body.

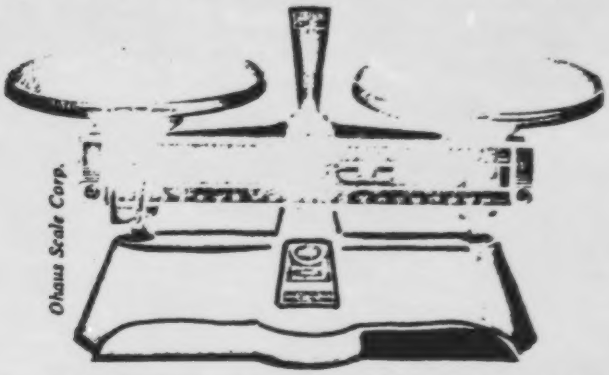

Ohaus Scale Corp.

Figure 6-5. A beam balance compares masses. The unknown mass is placed on the left and compared with known masses placed on the right. The masses are equal when the weights are equal causing the beam to be balanced.

The second method to determine the mass of a body is distinctly different. It uses the property of inertia. Suppose that a mass is placed on a completely frictionless, horizontal surface. Then a known force is applied to it. The magnitude of the mass is determined by carefully measuring the acceleration produced upon it by the known force. In accordance with Newton's second law of motion, $m = F/a$. C Mass measured in this way is said to be the inertial mass of the body in question. This second method to determine the mass of a body seldom is used because it involves both a frictionless surface and a difficult measurement of acceleration. The gravitational method of mass measurement is much easier and more popular.

Gravitational and inertial mass measurements give exactly the same numerical value for mass. However, the fact that gravitational and inertial mass always have the same magnitude for a given mass is not to be accepted as "natural." D

Briefly describe and classify the reasoning patterns involved in each item.

A:

B:

C:

D:

Please compare your ideas with those of your partner.

PART I DISCUSSION

Please follow the signs to the DISCUSSION area.

After working on Modules 1 to 4, you undoubtedly have unanswered questions, unresolved concerns, and possible uncertainties about what you have read, seen, and heard. In this discussion we should like you to bring these matters to the attention of your discussion leader and fellow participants so that your entire group may examine them. We hope that most items will be taken care of, at least partially. Since developmental theory has been applied to science teaching by only a few people and for a short period of time, no one has complete answers to some of the questions that may arise.

At the conclusion of the discussion, please proceed to Module 5 and pick up the instructional materials for your specific content area.

MODULE 4
BIOLOGY TEXTS AND REASONING PATTERNS

Introduction

The three preceding modules introduced you to concrete and formal patterns of reasoning. To help you recognize reasoning patterns required when your students read their texts, we have selected excerpts from three popular biology textbooks for you to read and analyze. Some of the passages require only concrete reasoning patterns while others require formal patterns. We have made no effort at this point to evaluate any text as a whole and to indicate whether or not the students' preparation for the quoted selection is adequate. The development of biology concepts and its relation to students' reasoning patterns will be taken up in Module 7.

Objective

To assist you in classifying biology text passages in regard to their requirements for concrete and formal reasoning.

Procedure

Choose a partner with whom you will work closely and exchange ideas. Evaluate the demands placed on students' reasoning by the first two excerpts. Compare your views with ours that immediately follow each excerpt. Then read Excerpt 3 and answer the questions concerning it. Discuss your answers with your partner.

Following this, proceed to the designated discussion area for a review of Modules 1-4. At the discussion's conclusion, proceed to Module 5.

Instructional Materials

Excerpt 1. From Biology: Living Systems, Oram R., Hummer, P. and Smoot, R., Charles E. Merrill Publishing Co., Columbus, 1973, pp. 656-658.

28:1 Evolution of a Forest

Usually the first stage in a succession of major importance involves very hardy organisms. They must be autotrophs which are capable of growing under adverse conditions. The first stage of succession is called the *pioneering stage*.

Hardy organisms are the first to invade a new area.

Consider the evolution of a community in New England.
A Community life may begin with lichens growing on bare rock. Lichens produce acids which begin to break the rock into small particles. As the lichens die, decomposers break them down. This decomposed organic material enriches the particles to make it a simple soil. Later more complex plants such as mosses, grasses, ferns, and shrubs appear.
B Their decay increases the humus content of the soil and makes it more complex and rich. Also, animals such as insects and worms add to the richness of the soil.
C Eventually trees such as pines or oaks occupy the area. As the community changes, the variety of animal life increases. As the soil continues to become richer, the pines and oaks are crowded out in the shade of beeches and maples.

Each stage of an ecological succession is characterized by a more complex set of plants and animals.

D Beeches and maples eventually dominate the community (Figure 28-1). They are known as the *dominant species*. This final stage in the evolution of the community is called the *climax community*.

A climax community is stable and usually has a dominant plant species.

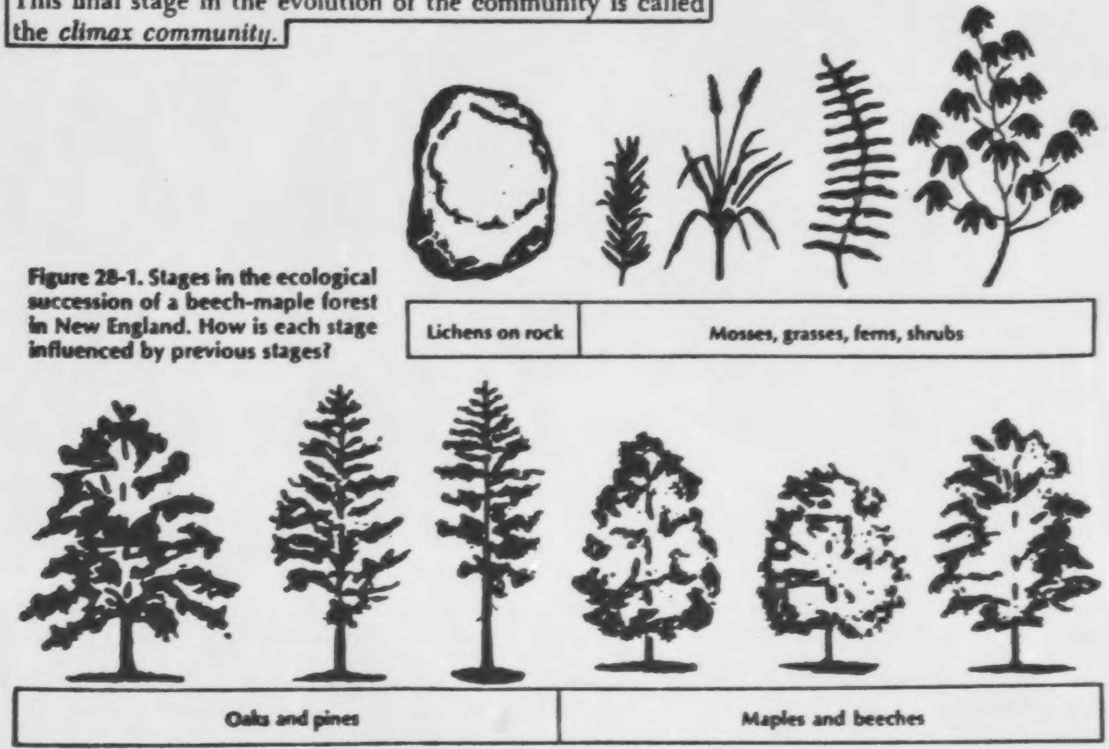


Figure 28-1. Stages in the ecological succession of a beech-maple forest in New England. How is each stage influenced by previous stages?

Commentary

The reader is required to imagine a series of changing plant types that inhabit a particular area (A). Although there may be no immediate experiences available to demonstrate this succession, the examples used are familiar ones and imagining these changes through time does not demand formal reasoning. The concrete reasoning patterns of serial ordering (placing plant types into a series ranging from simple to complex) and classification are sufficient.

Notice, however, that the passage leaves a number of implied questions unanswered. For example, it is stated that decay of some plants enriches the soil (B) and eventually pines and oaks occupy the area (C). But why? Why doesn't this soil enrichment just make it possible for more mosses and grasses to live there? Clearly an answer requires more than description (concrete reasoning). This suggests that describing succession may only involve concrete reasoning, but understanding the process requires more.

Notice also that in the last paragraph (D) it is stated that Beeches and Maples eventually dominate the community and that this is the final stage in succession. But why don't some other trees replace the Beeches and Maples? Again, concrete reasoning is sufficient to describe the state of affairs, but formal reasoning would be needed to understand the subtle nature of the "final" conditions in which the organisms exist in a self-perpetuating equilibrium with the physical habitat.

Excerpt 2. From the BSCS Yellow Version, 3rd Edition, Harcourt, Brace, Javanovich, New York, 1973, p. 611.

27–1 Gregor Mendel. The rules that he discovered for the inheritance of traits in peas have been found to apply to many other organisms.

The Work of Mendel

Gregor Mendel (Figure 27–1) grew up in an agricultural district of what is today Czechoslovakia. Quite early he was attracted to the monastic life. He was ordained an Augustinian priest at the age of twenty-five. Later he took additional training at the University of Vienna and taught in the high school in the town of Brünn for some years. It was during these years that he kept a small garden plot at the monastery and carried out his experiments with garden peas. These were the experiments that threw the first clear light on the nature of heredity. His results were published in 1865.

A

Mendel spent several years making sure that he had pure strains of pea plants. He did this by allowing plants with certain traits to produce seeds by self-pollination. If the offspring always had the same trait he knew that they were *true-breeding* or *pure* for this trait.

B

Mendel's experiments with these plants were unusual in three important ways:

C

1. He repeated his crosses (or matings) of different pure strains many times. This provided lots of data.

D

2. Mendel used mathematics to analyze his data and then to arrive at a hypothesis explaining his results.

E

3. He limited his study of each cross to a single difference at a time. In other words, each cross was between two types of plants that had a contrasting trait. For example, he studied round and wrinkled seeds, or tall and dwarf plants. Mendel made no attempt to study everything about the offspring at once.

There is another point you should keep in mind. When Mendel began his experiments, biologists knew nothing of chromosomes or the processes of cell division. The principles Mendel established were based solely on the evidence from breeding experiments.

Mendel chose garden peas for his experiments because he had found they have many desirable features. The plants are easy to cultivate and cross. Also, the length of a generation is reasonably short. Numerous varieties of pea plants were available, and the offspring of crosses between these different varieties are fertile. That is, the offspring are able to reproduce successfully. Of great importance, the pea flower is usually self-pollinating. It is not easily cross-pollinated by bees or other insects. Can you guess why this was important?

F

Commentary

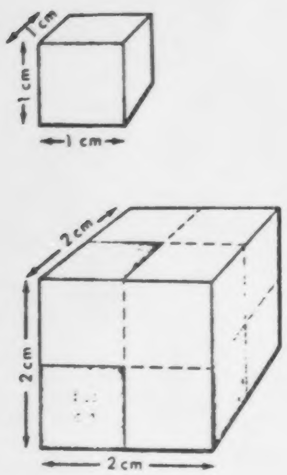
In the second paragraph, the notion of "pure strains of pea plants" is presented in two ways, one requiring formal patterns, the other concrete. Formal patterns are required to understand why self-pollination results in the reappearance of a given trait (A), whereas only concrete patterns are required to grasp and to use the operational definition of offspring always having the same trait (B).

Also in (A), why did Mendel spend "several years making sure that he had pure strains?" Why not several days or several hours? Although concrete patterns would suffice to understand the answer to this question, they would not suffice for raising the question -- for going beyond the given statement.

In Item 1 (C) the reader would have to recognize the probabilistic nature of phenomena to appreciate the value of having lots of data. This requires formal reasoning. Referring to Item 2 (D), formal reasoning, would also be required to appreciate Mendel's use of mathematics as an explanatory model for his data. Further, the formal reasoning pattern underlying the control of variables would be needed to understand the necessity for Mendel to limit his study of each cross to a single difference at a time -- Item 3 (E).

At the end of the excerpt (F) the reader is to guess why it is important that the pea flower not be easily cross-pollinated by bees or other insects. Why is this important? Does correctly answering this question require formal reasoning?

Excerpt 3. From Exploring Life Science, W. Thurber, R. Kilburn and P. Howell, Allyn and Bacon Inc., Boston, 1975, p. 33.



Cell Size and Food Intake. The rate that food molecules diffuse into a cell is believed to depend on the surface area of the cell. Analyze the problem of diffusion for cells of different sizes by making two model cells of clay. Cut one cube 1 centimeter (3/8") on each side, and the other 2 cm (3/4") on each side. How do the weights of the two cubes compare? A

Imagine living cells the size of the clay cubes. Compare the amounts of food each cell would use, assuming that the amount of food doubles as the weight doubles. B

Compare the surface area of each cube (an area of 1 square centimeter is shown by the shaded area on each cube here). Which cube has the greater surface area for its weight? Which cell can take in more food for its weight, a large cell or a small cell? C

This analysis of the food problems of large and small cells is based on at least two assumptions. Identify two assumptions and discuss how the conclusions would change if either assumption were proven incorrect. D Does this analysis prove why cells are small? Discuss your answer.

Briefly describe and classify the reasoning patterns involved in each item.

A:

B:

C:

D:

Please compare your ideas with those of your partner.

PART I DISCUSSION

Please follow the signs to the DISCUSSION area.

After working on Modules 1 to 4, you undoubtedly have unanswered questions, unresolved concerns, and possible uncertainties about what you have read, seen, and heard. In this discussion we should like you to bring these matters to the attention of your discussion leader and fellow participants so that your entire group may examine them. We hope that most items will be taken care of, at least partially. Since developmental theory has been applied to science teaching by only a few people and for a short period of time, no one has complete answers to some of the questions that may arise.

At the conclusion of the discussion, please proceed to Module 5 and pick up the instructional materials for your specific content area.

MODULE 4
GENERAL SCIENCE TEXTS AND REASONING PATTERNS

Introduction

The three preceding modules introduced you to concrete and formal patterns of reasoning. To help you recognize reasoning patterns required when your students read their texts, we have selected excerpts from three general science textbooks for you to read and analyze. Parts of the passages require only concrete reasoning patterns while others require formal patterns. We have made no effort at this point to evaluate any text as a whole and to indicate whether or not the students' preparation for the quoted selection is adequate. The development of general science concepts and its relation to students' reasoning patterns will be taken up in Module 7.

Objective

To assist you in classifying general science text passages in regard to their requirements for concrete and formal reasoning.

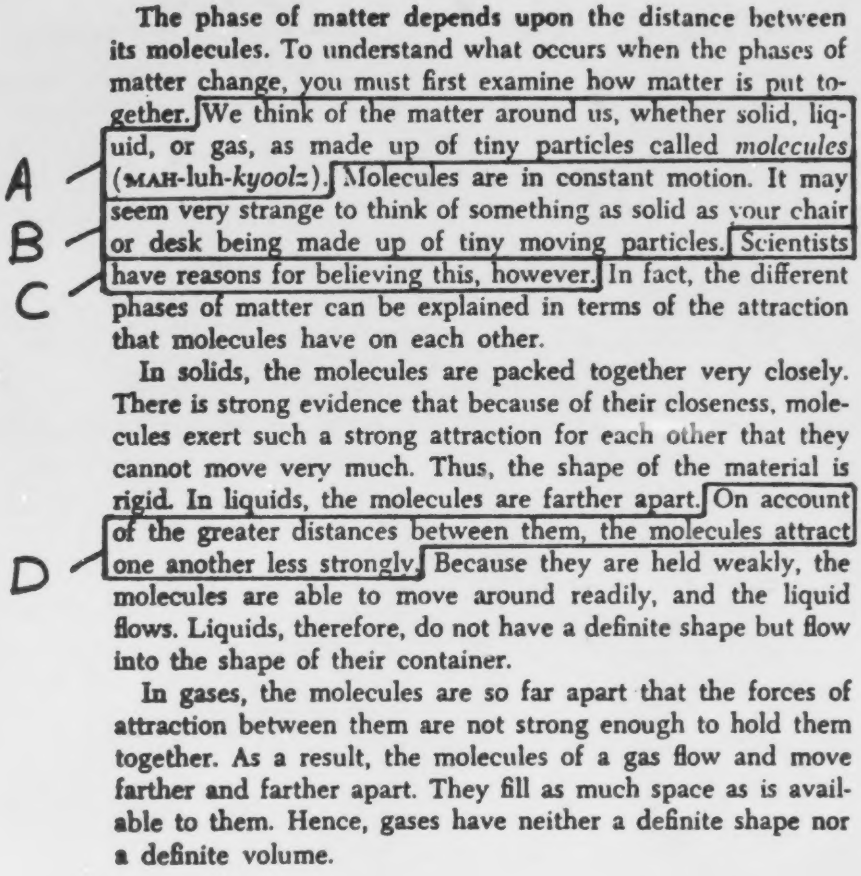
Procedure

Choose a partner with whom you will work closely and exchange ideas. Evaluate the demands placed on students' reasoning by the first two excerpts. Compare your views with ours that immediately follow each excerpt. Then read Excerpt 3 and answer the questions concerning it. Discuss your answers with your partner.

Following this, proceed to the designated discussion area for a review of Modules 1-4. At the discussion's conclusion, proceed to Module 5.

Instructional Materials

Excerpt 1. From Modern Science: Matter, Energy and Space, S. Blanc, et. al, Holt, Rinehart and Winston, New York, 1971, p. 13.



The phase of matter depends upon the distance between its molecules. To understand what occurs when the phases of matter change, you must first examine how matter is put together. We think of the matter around us, whether solid, liquid, or gas, as made up of tiny particles called *molecules* (MAH-luh-*kyoolz*). Molecules are in constant motion. It may seem very strange to think of something as solid as your chair or desk being made up of tiny moving particles. Scientists have reasons for believing this, however. In fact, the different phases of matter can be explained in terms of the attraction that molecules have on each other.

In solids, the molecules are packed together very closely. There is strong evidence that because of their closeness, molecules exert such a strong attraction for each other that they cannot move very much. Thus, the shape of the material is rigid. In liquids, the molecules are farther apart. On account of the greater distances between them, the molecules attract one another less strongly. Because they are held weakly, the molecules are able to move around readily, and the liquid flows. Liquids, therefore, do not have a definite shape but flow into the shape of their container.

In gases, the molecules are so far apart that the forces of attraction between them are not strong enough to hold them together. As a result, the molecules of a gas flow and move farther and farther apart. They fill as much space as is available to them. Hence, gases have neither a definite shape nor a definite volume.

Commentary

The initial paragraph (A) of this excerpt introduces "tiny particles" for the first time in the text. The reader is told about molecules and their motion (B), but is given no evidence -- just the affirmation -- that scientists have reasons for believing this (C). No reasoning is required here -- just faith.

If, however, the reader were given evidence to support the kinetic-molecular theory, then relating the assumptions to the consequences would require hypothetico-deductive thought. That approach would make use of formal reasoning patterns.

Application of the molecular hypothesis to the phases of matter in the second and third paragraphs makes use of the relation between strength of attraction and inter-particle distance: the greater the distance, the smaller the force (D). When used qualitatively, this correspondence requires only concrete reasoning. But understanding the correspondence as an unproven hypothesis used as a basis for deduction and empirical test would require formal hypothetico-deductive thought. Also, a quantitative understanding of the correspondence would make use of proportional reasoning - another aspect of formal thought.

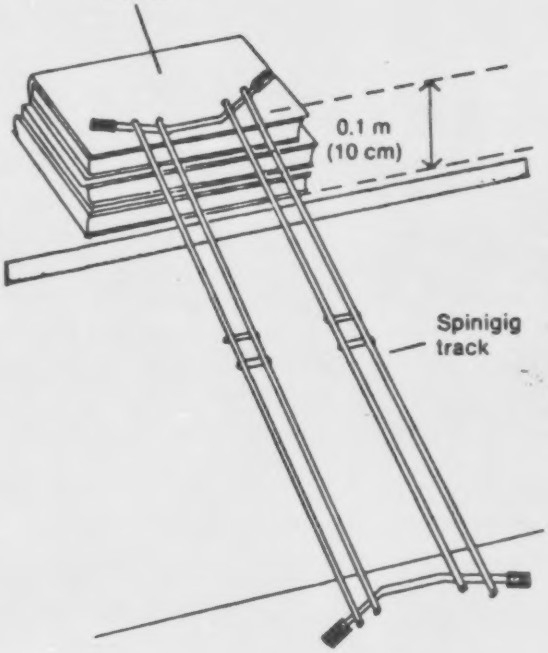
Excerpt 2. From Probing the Natural World, Volume 1, Intermediate Science Curriculum Study, Silver Burdett Co., 1970, pp. 81-86.

A — Has anyone ever told you that you have lots of "energy"? More than likely someone has, because this is a very common expression. But what does it mean? Just what is energy anyway? Before you knew the meaning of work, you couldn't answer the question about the meaning of energy. B — But now you're ready to develop an operational definition for this common word that very few people really understand.

C — To do the next activities, you will need the help of a partner and this equipment:

1 spinigig track
1 spinigig kit
1 cup
4 sinkers
1 piece of thread, about 1 meter long
1 piece of string, about 1 meter long
1 meterstick
1 half-kilogram mass
5 paper-clip hooks
15 nails
1 force-measurer with scales and blades

Your first problem will be to study what happens as your spinigig rolls down a slanted track. Activity 8-1 shows you how to set up the track.



(A series of experiments using the spinigig is described.)

D — The spinigig didn't look any different after you lifted it onto the track than it looked when it was on the table. But after the spinigig was lifted, it could do something that it could not do at the bottom of the track; it could lift the sinker.

A scientist would say that when you lifted the spinigig, you gave it more energy (how much more depends upon how far it has been lifted). E — By "energy" he would mean "the ability to do work." As long as the spinigig is above the bottom of the track, it can do work on the sinkers.

Commentary

The beginning of the excerpt (A) asks the reader to identify the meaning he or she attaches to the term "energy." Having readers become aware of the significance of the words they use is very important, but asking them to derive this meaning from their own reasoning involves the use of formal reasoning patterns.

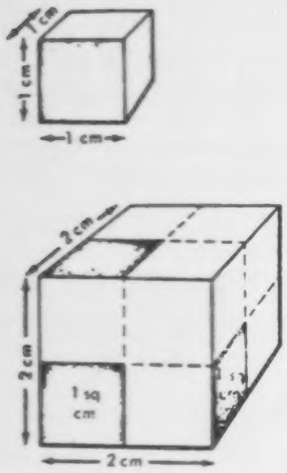
Developing an operational definition of energy (B) in effect avoids the need for formal reasoning patterns. Only concrete reasoning is needed to "operationally" (i.e., concretely) define energy. However, it is certainly possible to follow the operational definition by the use of concrete reasoning and fail to appreciate the meaning of energy developed by the use of formal reasoning.

Carrying out the series of experiments (C) according to the very explicit instructions provided (not included here) requires concrete reasoning patterns.

Formal reasoning is required to understand (D) where the student has to realize that the spinigig could do more when it was lifted, even though it looked the same!

The definition of energy in terms of work at the very end of the passage (E) uses one concept to define another, and it does not make direct reference to familiar actions and examples. For this reason as well, a complete understanding of the excerpt requires formal reasoning.

Excerpt 3. From Exploring Life Science, W. Thurber, R. Kilburn and P. Howell Allyn and Bacon Inc., Boston, 1975, p. 33.



Cell Size and Food Intake. The rate that food molecules diffuse into a cell is believed to depend on the surface area of the cell. Analyze the problem of diffusion for cells of different sizes by making two model cells of clay. Cut one cube 1 centimeter (3/8″) on each side, and the other 2 cm (3/4″) on each side. How do the weights of the two cubes compare? —A

Imagine living cells the size of the clay cubes. Compare the amounts of food each cell would use, assuming that the amount of food doubles as the weight doubles. —B

Compare the surface area of each cube (an area of 1 square centimeter is shown by the shaded area on each cube here). Which cube has the greater surface area for its weight? Which cell can take in more food for its weight, a large cell or a small cell? —C

This analysis of the food problems of large and small cells is based on at least two assumptions. Identify two assumptions and discuss how the conclusions would change if either assumption were proven incorrect. —D Does this analysis prove why cells are small? Discuss your answer.

Briefly describe and classify the reasoning patterns involved in each item.

A:

B:

C:

D:

Please compare your ideas with those of your partner.

MODULE 4
EARTH SCIENCE TEXTS AND REASONING PATTERNS

Introduction

The three preceding modules introduced you to concrete and formal patterns of reasoning. To help you recognize reasoning patterns required when your students read their texts, we have selected excerpts from three popular earth science textbooks for you to read and analyze. Parts of the passages require only concrete reasoning patterns while others require formal patterns. We have made no effort at this point to evaluate any text as a whole and to indicate whether or not the students' preparation for the quoted selection is adequate. The development of earth science concepts and its relation to students' reasoning patterns will be taken up in Module 7.

Objective

To assist you in classifying earth science text passages in regard to their requirements for concrete and formal reasoning.

Procedure

Choose a partner with whom you will work closely and exchange ideas. Evaluate the demands placed on students' reasoning by the first two excerpts. Compare your views with ours that immediately follow each excerpt. Then read Excerpt 3 and answer the questions concerning it. Discuss your answers with your partner.

Following this, proceed to the designated discussion area for a review of Modules 1-4. At the discussion's conclusion, proceed to Module 5.

Instructional Materials

Excerpt 1. From ESCP: Investigating the Earth, revised edition, M. Harris, et. al., 1973, pp. 330-331.

Discovery of the property of radioactivity soon led to other discoveries about radioactive substances, including rates of decay, the amount of energy generated, and products of the decay process. In 1907 the American chemist and physicist, B. B. Boltwood, discovered that uranium decays, forming lead as the final product. Boltwood concluded that the age of a particular mineral can be found, if you measure the amount of the parent material (uranium) in it and the amount of the decay product (lead). You would also have to calculate the rate of decay of the parent material.

One popular radioactive dating method is based on the breakdown of uranium-238 (^{238}U). Uranium-238 decays through a series of 14 steps, ending up as lead-206 (^{206}Pb). As the breakdown from uranium progresses, the amount of lead increases. The rate of decay of ^{238}U and other unstable elements used for dating have been precisely determined and found to be constant throughout geologic time. A

After a mineral containing uranium atoms is formed, the products of uranium decay begin to accumulate in the mineral. The age of the mineral is calculated by determining the ratio of the parent material (^{238}U) to the end product (^{206}Pb). B Elaborate analytical equipment must be used for determining uranium to lead ratios. In applying this method, it is assumed that none of the lead escapes from the mineral, that no outside lead is added, and that no lead from a non-radioactive source was present to begin with. If any of these conditions have affected the sample being tested, the results will not be accurate. C Can you suggest how the ages obtained in dating three samples might be affected if each of the samples was altered in one of the above ways?

Commentary

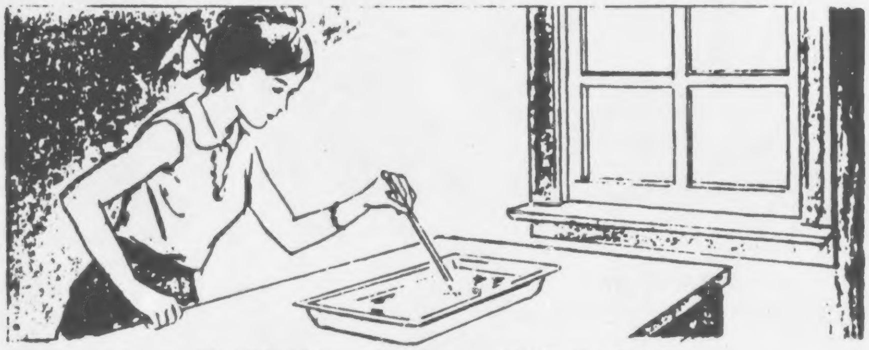
Although the material is consistently presented in a descriptive and qualitative manner, formal reasoning patterns would be needed to grasp the deceptively simple statements found in the text.

Determining time in terms of a decay rate and the amounts of, say U-238 and Pb, is only qualitatively discussed and this in an incomplete fashion (A). Partial understanding might be accessible to students who grasp that the amount of Pb will be due to the two variables, elapsed time, and the initial amount of U-238, since the decay rate is asserted to be constant. The reasoning required might be, "The older the sample, the more Pb for a given initial amount of U-238." Taken individually, concrete patterns might suffice; taken together, formal patterns are required.

A comparison of ages of minerals by a comparison of ratios of parent materials to end products (B) involves proportional reasoning -- a formal reasoning pattern.

The concluding remarks on the conditions required to obtain valid results (C) also make use of the formal reasoning patterns underlying controlling variables.

Excerpt 2. From Exploring Earth Science, W. A. Thurber and R.E. Kilburn, Allyn and Bacon, Inc., 1970, p. 274.



ENERGY FROM SUNLIGHT

Our atmosphere circulates constantly, transporting heat and water vapor from one place to another, and producing the conditions we call *weather*. All this atmospheric movement requires energy which is provided by the sun in the form of radiation, both visible and invisible. However, radiant energy cannot directly set air in motion; it must first be changed to heat energy in order to produce convection. Thus, the study of weather begins with the change of radiant energy to heat energy.

A

Absorption of Radiant Energy. Pour water at room temperature into a shallow tray. Set the tray in sunlight for 10 minutes. Measure the temperature change in degrees Celsius (1.8°F = 1.0°C). Then measure the volume of the water in cubic centimeters (one measuring cup contains about 250 cubic centimeters). Calculate the calories absorbed by the water (assume that one calorie is the amount of heat needed to warm one cubic centimeter of water one degree Celsius).

B

C

Energy Value of Sunlight. Meteorologists estimate that sunlight entering the atmosphere can provide about two calories per minute for each square centimeter of surface. This value is called the *solar constant*, although it is not exactly constant because of sunspots.

D

Measure the area of the tray used in the last experiment. How much heat was absorbed by each square centimeter of surface? How much heat did each square centimeter absorb per minute?

E

Commentary

The introductory paragraph (A) refers to an atmospheric system driven by radiant energy from the sun. Concrete reasoning patterns will structure the information as a linear causal chain. The mention of invisible radiation will pose a problem (how do you know it's there?) as will the distinction between light and heat (sunlight feels warm, so why speak of transformation of energy?). Indeed, the general concept of energy is both abstract and formal (in Piaget's sense), although particular manifestations of energy can be qualitatively apprehended with concrete reasoning patterns.

Following the explicit directions given at the beginning of the next paragraph (B) requires neither concrete nor formal reasoning. The calorie is introduced (C) without prior background and exemplifies use of formal patterns. The reference to sunspots (D) is, apparently, the only such mention in the text. Thus, the relation of sunspots to the solar constant is likely to be incomprehensible regardless of which reasoning patterns are brought to bear.

The mathematical computations called for in the last paragraph (E) again require formal patterns to be understood, or concrete patterns to be used in a rote fashion.

Excerpt 3. From Focus on Earth Science, M. Bishop, P. Lewis and B. Sutherland, C.E. Merrill Pub. Co., 1976, p. 64.

THE EARTH-MOON SYSTEM

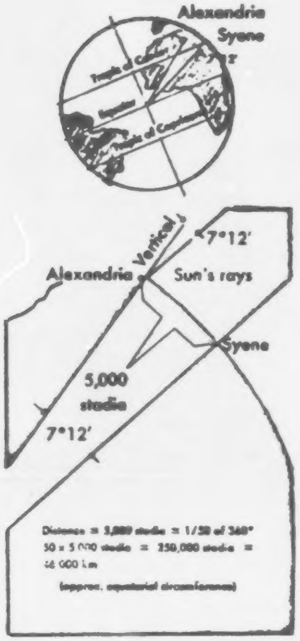

Alexandria
Syene
Tropic of Cancer
Equator
Tropic of Capricorn
Vertical
7°12′
Alexandria
Sun's rays
Syene
5,000 stadia
7°12′
Distance = 5,000 stadia = 1/50 of 360°
50 × 5,000 stadia = 250,000 stadia = 46,000 km
(approx. equatorial circumference)

Figure 3-12. Eratosthenes' nearly-accurate figures showed the earth's size to be much larger than early scientists believed.

Eratosthenes studied at the great learning center of Alexandria, Egypt. He knew that Syene (sie EE nee) was about 5000 stadia south of Alexandria. At noon on the vernal equinox, the sun shone directly into a deep well in Syene and cast no shadow. But on the same day in Alexandria, the sun did cast a shadow at noon. Eratosthenes used a vertical post to measure the angle of the sun's rays. He found the angle to be 7° 12′ in Alexandria. Because of the sun's great distance from Earth all rays reach us nearly parallel. Thus Eratosthenes reasoned that the earth must be curved. The sun's rays were perpendicular to the earth at Syene but made an angle with the earth at Alexandria (Figure 3-12). The angle of 7° 12′ is 1/50 of 360°, the circumference of a circle. Eratosthenes concluded that

$$\frac{7°12'}{360°} = \frac{7.2}{360} = \frac{1}{50}$$

the distance of 5000 stadia between Alexandria and Syene was 1/50 of the circumference of the earth. If stadia are converted to kilometers, Eratosthenes' measurement is about 42,656 km. Today, the accepted measurement of the earth is about 40,000 km. Modern sightings are made on a star rather than the sun.

A
B
C
D

Briefly describe and classify the reasoning patterns involved in each item.

A:

B:

C:

D:

Please compare your ideas with those of your partner.

MODULE 4
CHEMISTRY TEXTS AND REASONING PATTERNS

Introduction

The three preceding modules introduced you to concrete and formal patterns of reasoning. To help you recognize reasoning patterns required when your students read their texts, we have selected excerpts from three popular chemistry textbooks for you to read and analyze. Parts of the passages require only concrete reasoning patterns while others require formal patterns. We have made no effort at this point to evaluate any text as a whole and to indicate whether or not the students' preparation for the quoted selection is adequate. The development of chemistry concepts and its relation to students' reasoning patterns will be taken up in Module 7.

Objective

To assist you in classifying chemistry text passages in regard to their requirements for concrete and formal reasoning.

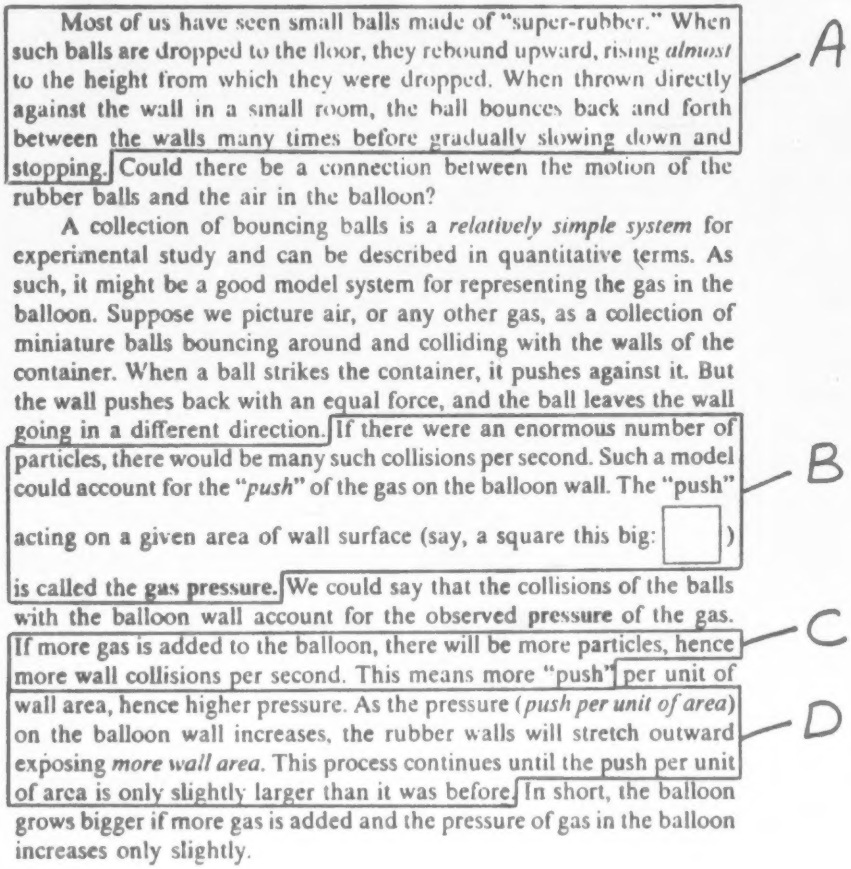
Procedure

Choose a partner with whom you will work closely and exchange ideas. Evaluate the demands placed on students' reasoning by the first two excerpts. Compare your views with ours that immediately follow each excerpt. Then read Excerpt 3 and answer the questions concerning it. Discuss your answers with your partner.

Following this, proceed to the designated discussion area for a review of Modules 1-4. At the discussion's conclusion, proceed to Module 5.

Instructional Materials

Excerpt 1. From Chemistry: Experimental Foundations, 2nd edition, R. Parry et. al., Prentice-Hall, Englewood Cliffs, 1975, p. 11.



Most of us have seen small balls made of "super-rubber." When such balls are dropped to the floor, they rebound upward, rising *almost* to the height from which they were dropped. When thrown directly against the wall in a small room, the ball bounces back and forth between the walls many times before gradually slowing down and stopping. Could there be a connection between the motion of the rubber balls and the air in the balloon?

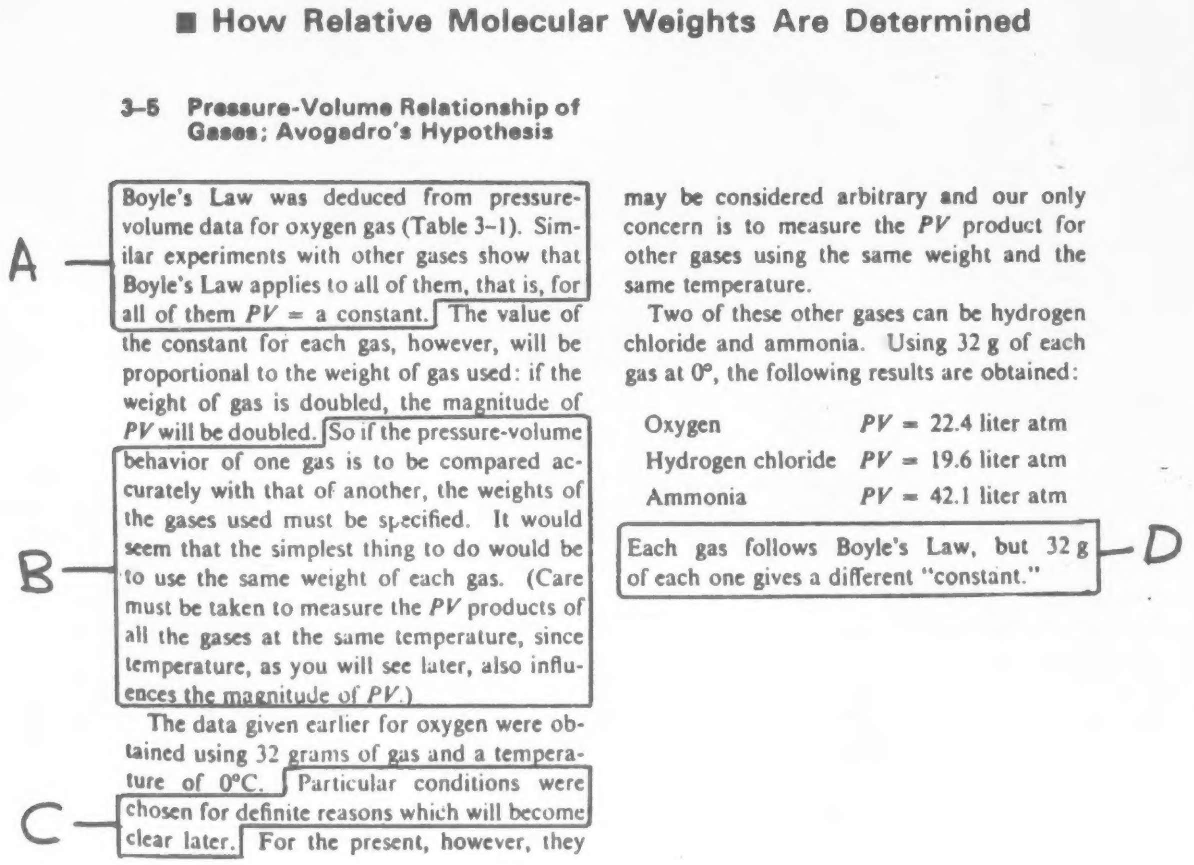
A collection of bouncing balls is a *relatively simple system* for experimental study and can be described in quantitative terms. As such, it might be a good model system for representing the gas in the balloon. Suppose we picture air, or any other gas, as a collection of miniature balls bouncing around and colliding with the walls of the container. When a ball strikes the container, it pushes against it. But the wall pushes back with an equal force, and the ball leaves the wall going in a different direction. If there were an enormous number of particles, there would be many such collisions per second. Such a model could account for the "*push*" of the gas on the balloon wall. The "push" acting on a given area of wall surface (say, a square this big: □) is called the gas pressure. We could say that the collisions of the balls with the balloon wall account for the observed pressure of the gas. If more gas is added to the balloon, there will be more particles, hence more wall collisions per second. This means more "push" per unit of wall area, hence higher pressure. As the pressure (*push per unit of area*) on the balloon wall increases, the rubber walls will stretch outward exposing *more wall area*. This process continues until the push per unit of area is only slightly larger than it was before. In short, the balloon grows bigger if more gas is added and the pressure of gas in the balloon increases only slightly.

Commentary

Although this was only meant to be an introductory account as much concerned with the concept of a model per se as with gas pressure (treatedd mathematically in a later chapter), the treatment is rather formal. Bouncing super-rubber and exerting a push (A) are concrete enough, but formal reasoning is required to infer pressure from a time-averaged superposition of the minute effects of very many tiny unobserved super-balls (implied by B). The qualitative effect of more gas giving rise to a greater push is also concrete (C). Yet the new equilibrium state of the balloon is described in a manner (D) which requires much inference, hence formal reasoning, and which even conceals these inferences (What are they?).

This account of gas pressure could only be fully comprehended by the use of formal reasoning patterns applied with a great deal of facility since the information is so compact. A student limited to concrete reasoning patterns would appreciate the discussion to a slight extent--for instance, more particles means more collisions and more force. This and some other isolated relationships are inadequate to make the excerpt comprehensible or to stimulate the development of formal reasoning patterns.

Excerpt 2. From Chemistry: An Investigative Approach, F. Cotton and L. Lynch, Houghton Mifflin Co., New York, 1968, p. 51.



How Relative Molecular Weights Are Determined

3-5 Pressure-Volume Relationship of Gases; Avogadro's Hypothesis

Boyle's Law was deduced from pressure-volume data for oxygen gas (Table 3-1). Similar experiments with other gases show that Boyle's Law applies to all of them, that is, for all of them PV = a constant. The value of the constant for each gas, however, will be proportional to the weight of gas used: if the weight of gas is doubled, the magnitude of PV will be doubled. So if the pressure-volume behavior of one gas is to be compared accurately with that of another, the weights of the gases used must be specified. It would seem that the simplest thing to do would be to use the same weight of each gas. (Care must be taken to measure the PV products of all the gases at the same temperature, since temperature, as you will see later, also influences the magnitude of PV.)

The data given earlier for oxygen were obtained using 32 grams of gas and a temperature of 0°C. Particular conditions were chosen for definite reasons which will become clear later. For the present, however, they may be considered arbitrary and our only concern is to measure the PV product for other gases using the same weight and the same temperature.

Two of these other gases can be hydrogen chloride and ammonia. Using 32 g of each gas at 0°, the following results are obtained:

Oxygen	PV = 22.4 liter atm
Hydrogen chloride	PV = 19.6 liter atm
Ammonia	PV = 42.1 liter atm

Each gas follows Boyle's Law, but 32 g of each one gives a different "constant."

Commentary

At the beginning of the excerpt (A), formal reasoning patterns are demanded since numerical data are modeled by mathematical rather than qualitative relationships. Proportions require formal patterns and so does the very abstract notion of "pressure - volume behavior," all the more the idea of accurately comparing such behaviors.

Notice that the second paragraph admits the arbitrariness of the preceding description, but asks the reader to accept the authors' judgment without question until "later" (C). Accepting such information as a working hypothesis requires formal reasoning.

Consider the following questions in relation to the excerpt:

(A) What is the reasoning pattern applied in (B)?

(B) What significance does the conclusion (D), the different "constant" in the empirical relationships for PV, have for the reader of this passage?

Excerpt 3. From Chemistry, G.H. Miller, Harper Row, 1969, p. 17-19.

LAW OF DEFINITE COMPOSITION

In 1799 Joseph Louis Proust (1754 1826) showed that artificially prepared copper carbonate was identical in composition to that found in nature, and on the basis of this and numerous other experiments he was able to conclude that "the properties of pure compounds are invariable as is the ratio of their constituents." In simpler terminology the law can be stated: A given compound always contains the same elements in the same ratio by weight. Table 3-2 lists the percentage composition of the elements in a number of common compounds. A

TABLE 3-2 CHEMICAL COMPOSITION OF SOME COMMON COMPOUNDS

Compound	Formula	Weight Percent of Each Element					
Table salt	NaCl	Na	39.3	Cl	60.7		
Sugar (sucrose)	$C_{12}H_{22}O_{11}$	C	42.2	H	6.4	O	51.4
Carbon dioxide	CO_2	C	27.3	O	72.7		
Alcohol (ethyl alcohol)	CH_3CH_2OH	C	52.2	H	13.0	O	34.8
Lye (sodium hydroxide)	NaOH	Na	57.5	O	40.0	H	2.5
Dimethyl ether	CH_3OCH_3	C	52.2	H	13.0	O	34.8
Washing soda	Na_2CO_3	Na	43.4	C	11.3	O	45.3

No matter from what source ordinary water is obtained, the pure compound always contains 88.81 percent oxygen and 11.19 percent hydrogen. B These constant compositions are amenable to explanation by the atomic theory, which says that water must consist of a combination of oxygen and hydrogen atoms and that these atoms have united to form molecules. C The atoms of hydrogen and of oxygen are discrete particles having certain definite but different masses. When they unite to form molecules they must do so as discrete units. It is not possible for half a hydrogen atom to unite with one third of an oxygen atom; it is only possible for atoms to unite in a manner such that the ratio of the number of atoms of each element are small whole numbers. D In the case of water we know that two atoms of hydrogen unite with one atom of oxygen to form one molecule of water. The total mass of a water molecule must consist of the mass of two atoms of hydrogen and one atom of oxygen; hence the percent composition of the components of water is invariant.

The formation of a water molecule from atoms can be illustrated by writing a chemical equation:

$$2H + 1O \rightarrow 1HOH$$

The arrow means yields, produces, or gives. The number before the symbol or formula notation indicates the number of atoms or molecules; if the number is 1, it is omitted:

$$2H + O \rightarrow HOH$$

Briefly describe and classify the reasoning patterns involved in each item.

A:

B:

C:

D:

Please compare your ideas with those of your partner.

PART I DISCUSSION

Please follow the signs to the DISCUSSION area.

After working on Modules 1 to 4, you undoubtedly have unanswered questions, unresolved concerns, and possible uncertainties about what you have read, seen, and heard. In this discussion we should like you to bring these matters to the attention of your discussion leader and fellow participants so that your entire group may examine them. We hope that most items will be taken care of, at least partially. Since developmental theory has been applied to science teaching by only a few people and for a short period of time, no one has complete answers to some of the questions that may arise.

At the conclusion of the discussion, please proceed to Module 5 and pick up the instructional materials for your specific content area.

PART II
TEACHING FOR SELF-REGULATION

5. Self-Regulation and the Learning Cycle
6. The Laboratory and Self-Regulation
7. Concrete and Formal Concepts
8. Tests and Self-Regulation

MODULE 5
SELF-REGULATION AND THE LEARNING CYCLE

Introduction

The central question raised by this workshop so far is, "How can we assist students in developing and using formal reasoning patterns?" Before we describe specific science teaching procedures that can be especially valuable, we shall take a closer look at the process of self-regulation. This process is essential to the formation of new reasoning patterns. Immediately afterwards we describe the learning cycle approach to teaching that encourages self-regulation. Making students aware of their own reasoning is an important part of such teaching.

Objectives

To give you an understanding of self-regulation.

To assist you in using the "learning cycle" approach to teaching for self-regulation.

Procedure

Join with a group of two to three teachers for this entire module. The introductory group activity will be followed by individual reading of essays on self-regulation and the learning cycle. To conclude this module, we suggest you discuss these two topics and their implications with your colleagues. Then, please, continue with Module 6.

Instructional Materials

1. Exploration

To simulate the experience of a student using concrete reasoning patterns in a science class requiring formal thought, we have constructed a puzzle that requires you to make drawings while looking into a mirror. Few persons can immediately make drawings under these conditions. Most people can teach themselves to overcome their initial difficulty, but some have blocks that appear to prevent them from mastering the skill.

Join with your group to use the mirror puzzle and pages 5-3 and 5-4. Take turns drawing the patterns suggested. Try to become conscious of your own techniques while you are drawing. Also, observe carefully to identify your colleagues' learning strategies while they are working. After each person's turn is concluded, the "observers" might tell him what they thought he was trying to do, and he could then describe how he perceived his own efforts.

After everyone from your group has used the mirror puzzle, exchange ideas regarding your efforts and difficulties.

What direction and/or shape of line was easiest to draw?

Which was the most difficult?

What new procedures did you adopt?

What errors persisted in spite of your best efforts?

Did right vs. left-handed drawing seem to affect the result?

Did you try drawing with your eyes closed and find that it helped?

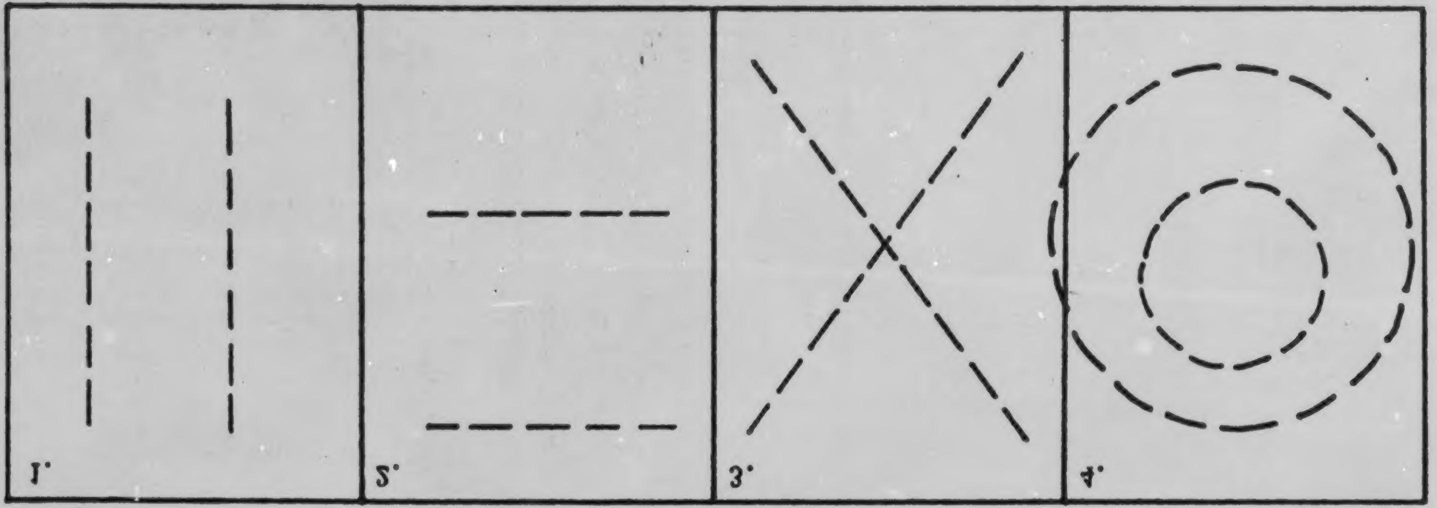
Did your thinking patterns change while you were using the puzzle?

What feedback from your actions was especially helpful?

Please stay with your group as you turn to page 5-5 for the essay on self-regulation.

5-3 Please trace each of these figures while looking only into the mirror.

Keep your pencil in contact with the paper as much as possible.

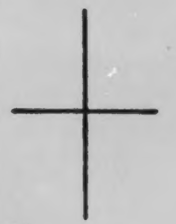


Please write your name while looking only into the mirror.

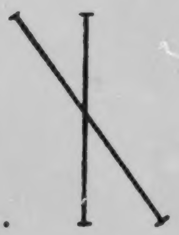
Write it so it appears normal when read in the mirror.

Please copy each of these figures one or more times in the rectangle beside the pattern.

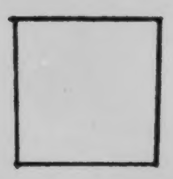
1.



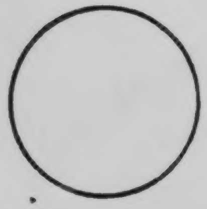
2.



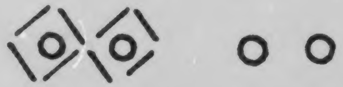
3.



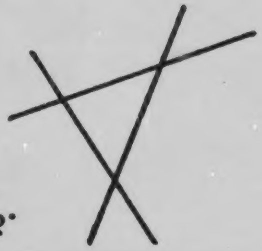
4.



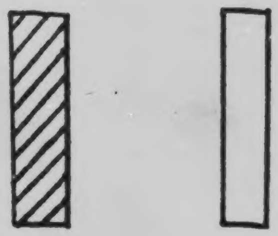
5.



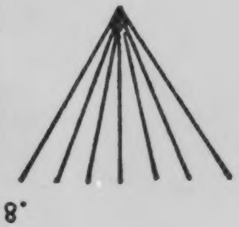
6.



7.



8.



2. Essay. Self-Regulation

When you approached the mirror puzzle, you were using perceptual and motor patterns developed in your childhood through direct visual feedback from your experiences in drawing without a mirror. Your responses to the reflected images may have been awkward at first, making you draw lines in the wrong directions. You interpreted the new experience with the mirror puzzle in terms of your old patterns.

Your initial difficulties may have made you pause and reflect upon your actions. You may have tried to take the relation of the mirror image to your hand and pencil into account, perhaps by concentrating on reference directions such as "away from your body" or "towards your hand." In other words, you introduced elements that were not obvious parts of the setup. Watching another member of the group may also have given you ideas on how to proceed.

Reflection, restructuring of tasks, and learning from others contributes to the formation of new reasoning patterns in the same way as they helped you with the mirror puzzle. We call this internal mental process self-regulation.* Ultimately, applying a new reasoning pattern to a variety of tasks stabilizes its use, just as the old reasoning patterns had been stabilized through practice with simpler tasks on which they had led to success.

Each reasoning pattern used by a person represents a relatively consistent approach to a class of similar problems. Feedback derived from the person's thoughts and actions on such problems strengthens the effective reasoning patterns. These patterns form an interrelated system of understandings and procedures generally reflecting a developmental stage. Repeated self-regulation relative to many reasoning patterns will eventually lead the individual to function on a higher developmental stage.

As another and very different example, consider the relationship of pizza price to pizza size. A child using concrete reasoning patterns will expect a simple, direct relationship of size and price. When asked about the price of a sixteen-inch pizza compared to an eight-inch one, he will predict that it costs twice as much, "Because it's twice as big." Imagine his dismay when he finds that the large pizza costs four times as much! How can that be explained other than in terms of extortion by the pizza parlor proprietor?

Consider also the physics student who has learned to predict the distance of free fall by substituting into the equation $s = (1/2)gt^2$ (concrete reasoning pattern). This student will be overwhelmed by the task of finding the height of fall of a body that starts from rest and travels half its path during the last second of fall. Introducing the total time as an intermediate variable is a formal reasoning pattern that makes the second problem much more difficult even though the physical phenomenon and basic law are the same.

---

*Self-regulation goes on all the time. It may involve reasoning patterns that deal with scientific tasks or with questions in other areas. In this module, we shall use the term to refer specifically to the formation of reasoning patterns of importance in science education.

Just as in your encounter with the mirror, the interactions of a person with the environment may lead to contradictions, i.e., expectations that are not confirmed by what actually happens. Then the stable state of mind is upset and a change in reasoning patterns can be brought about through self-regulation.

Self-regulation is an active process of forming new reasoning patterns that integrate new concepts and/or resolve apparent contradictions perceived in the framework of old reasoning patterns. Self-regulation involves the student in analyzing a problem situation, considering tentative solutions, evaluating their effectiveness, and using new approaches when the first trials are not successful. Awareness of one's own reasoning is very important for self-regulation that leads to formal reasoning patterns.

Whatever one's specific method of coping with a new challenge, when the changes required are not too great, one is likely to reorganize one's patterns of reasoning into more appropriate new ones. One may realize that if Mr. Short in the Ratio Puzzle is four buttons or six paper clips high, then each button -- one quarter of Mr. Short's height -- is equal to one-and-a-half paper clips. Confirmation of these new patterns through application to further experiences will maintain the new stable state until additional contradictions are encountered.

If the required changes in reasoning are great, however, a person may be helped by peers, teachers, or parents who can suggest more appropriate patterns.

> "It's the area of the pizza that determines the price, and the area varies as the square of the diameter."
>
> "The total time of falling is t and the time for falling the first half of the height is (t-1)."

Such direct teaching, however, is usually not effective unless the learner has had previous experiences with the ideas needed (area, functional relation of time and distance) and can subsequently test them against his own observations. He must get encouraging feedback from the environment to make sure that the interplay of thought and action, an essential part of self-regulation, continues until the new reasoning patterns are firmly established.

Could you have learned to draw the mirror figures, predict the cost of large pizza, or solve the free-fall problem by other teaching techniques? This question raises an important issue that divides learning theorists. Some would recommend that the learner only be given tasks after the solution method has been explained carefully. We believe that this approach limits the learning to the particular solution methods. Since the student does not have to search his repertoire and possibly replace inadequate reasoning patterns, these old patterns remain and are likely to be applied uncritically to the next problem they seem to fit.

In the next essay, we present the learning cycle approach for adapting instruction to encourage self-regulation. We have used it effectively with students at all levels. Of course, a learner who employs formal reasoning patterns in some areas of experience has an advantage. He is more likely to engage in self-regulation in a new domain because he is aware of his own reasoning, can recognize its shortcomings, apply procedures successful in other areas, and search more effectively for new patterns. To be helpful, a teaching program must strengthen these tendencies in all students and discourage unquestioning acceptance of poorly-understood principles and procedures.

3. Essay: The Learning Cycle

Suppose you are beginning your physics course's section on uniformly accelerated motion. Would you begin it by:

(a) Presenting a film that shows carts rolling down an inclined plane and golf balls falling freely (slow-motion photography), together with stroboscopic photographs, timing tapes, and graphs of speed and distance vs. time.

(b) Arranging for a laboratory period in which your students could use level or inclined air-tracks, springs, weights, falling golf balls, timing tapes, flexible ramps, polaroid cameras with strobe lights, and stop watches to observe accelerated motion under various conditions of their own choosing.

(c) Discussing with your students their own experiences with accelerated motion in automobiles, buses, airplanes, or elevators, and analyzing these observations.

(d) Presenting an explanation beginning with Newton's second law and deriving from it the relation between the constant accelearation, velocity, and distance moved by a particle subject to a constant force.

(e) Providing a laboratory where students carefully measure the distance intervals on a timer tape produced by a glider sliding down a slightly inclined air track, then graph the measurements and relate the slope of the graph to the angle of inclination of the track.

Certainly the resources available to you and the preparation of the students will influence your choice. Compare our comments below with yours and, if possible, with those of another participant.

(a) Films are popular ways of introducing a new topic. In this case, the film's content is similar to what students might observe in a laboratory of type (b) or (e) if they worked very conscientiously and carefully with good equipment. We would recommend the film be used after a laboratory period if laboratory materials are available. Films raise questions, provoke inquiry, or present contradictions less effectively than first hand laboratory experiences. Since paying attention to the film preempts their initiative, few students watching a film for the first time think critically about what they observe. Additionally, seeing a picture of an object or process does not carry the impact of handling the object or influencing the process oneself.

(b) We would highly recommend an approach of this kind, where the students have a great deal of freedom to use their own judgment, try out their own ideas, and learn from their own mistakes as they gain practical experience with the objects they will study theoretically later. The teacher can evaluate the students' reasoning patterns and later provide more direction or extend the autonomous investigations as needed.

(c) Even though this procedure appeals to the students' direct experience, the occurrence of uniformly accelerated motion is hard to isolate from the everyday events listed. A jet accelerating to take-off provides the best example we can think of. Yet it is very difficult for the passenger in the jet to be aware of the distance covered. While this discussion may be appropriate when motion in general is taken up, we consider it unsuitable at this time.

(d) This rather theoretical approach, often in the form of a lecture, would be completely inappropriate as the introduction to a new topic, because it takes for granted that the students have a good grasp of the distance, speed, acceleration, and force concepts. Furthermore, it depends on algebraic relationships that can only be understood through formal reasoning patterns.

(e) This type of laboratory prevents the students from asking their own questions and taking responsibility for satisfying their own curiosity. The reason for graphing the distances will not be clear at this time either. Such a laboratory would be more appropriate later in the instructional sequence, but even then it might better focus on sources of error or other deviations from uniform acceleration rather than on merely verifying the linear relationship of speed and elapsed time.

The recommended approach in (b) is an example of exploratory activity upon which later conceptual understandings can be built. It represents the EXPLORATION phase of a three-phase learning cycle based on current theories of learning and designed to encourage self-regulation. The three phases of the entire learning cycle are called EXPLORATION, CONCEPT INTRODUCTION, and CONCEPT APPLICATION.

During EXPLORATION, the students learn through their own actions and reactions in a new situation. In this phase they explore new materials and new ideas with minimal guidance or expectation of specific accomplishments. The new experience should raise questions that they cannot answer with their accustomed patterns of reasoning. Having made an effort that was not completely successful, the students will be ready for self-regulation.

The second phase, CONCEPT INTRODUCTION, starts with the introduction of a new concept or principle -- acceleration, Newton's second law -- that leads the students to apply new patterns of reasoning to their experiences. The concept may be introduced by the teacher, the textbook, a film, or another medium. This step, which aids in self-regulation, should always follow exploration and relate to the exploration activities. The film in alternative (a) above or the lecture in alternative (d) could serve as CONCEPT INTRODUCTION sessions following the laboratory activity (b). Students should be encouraged to develop as much of a new reasoning pattern as possible before it is explained to the class, but expecting students to introduce the complex ideas of modern science is unrealistic.

In the last phase of the learning cycle, CONCEPT APPLICATION, the students apply the new concept and/or reasoning pattern to additional examples. The measurement of acceleration of gliders on air tracks at various inclinations as in alternative (e) would be a good APPLICATION activity following the introduction of the acceleration concept. Other APPLICATION activities might concern the effects of friction and other forces acting on a body on an inclined plane.

The APPLICATION phase is necessary to extend the range of applicability of the new concept. CONCEPT APPLICATION provides additional time and experiences for self-regulation and stabilizing the new reasoning patterns. Without a number and variety of applications, the concept's meaning will remain restricted to the examples used during its definition. Many students may fail to abstract it from its concrete examples or generalize it to other situations.

In addition, APPLICATION activities aid students whose conceptual reorganization takes place more slowly than average, or who did not adequately relate the teacher's original explanation to their experiences. Individual conferences with these students to help identify and resolve their difficulties are especially helpful.

Note how the learning cycle, though based primarily on developmental principles, takes advantage of other learning theories also. Thus, the EXPLORATION phase permits learning by discovery, the CONCEPT INTRODUCTION phase allows learning from explanation, and the CONCEPT APPLICATION phase provides for learning by repetition and practice. All of these can contribute to self-regulation if students are allowed to benefit from each phase according to their individual abilities and needs. If a phase is eliminated or all students are expected to demonstrate specified uniform accomplishments after each one, then the overall effectiveness of the learning cycle will be compromised.

As another example of the learning cycle, we direct your attention to this essay. We did not begin with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies for accelerated motion according to your own experiences and preferences, to be compared with our ideas. That served as EXPLORATION. Next we described the three-phase learning cycle, the CONCEPT INTRODUCTION in this essay, with reference to the acceleration example. Your APPLICATION activities in this essay began with a look at the essay itself.

Next, examine this module as a whole. The mirror puzzle was intended to serve as exploration with respect to the concept of self-regulation. Then came the essay on self-regulation, which was the CONCEPT INTRODUCTION. The essay on the learning cycle was your first APPLICATION activity, which will be followed by further applications of self-regulation to the laboratory and to physics concept development in the next modules.

Finally, examine the entire workshop outline, which was also planned according to a learning cycle. We believe that this examination will form an additional APPLICATION activity for you.

Review Questions

You have studied self-regulation and the learning cycle of EXPLORATION CONCEPT INTRODUCTION, CONCEPT APPLICATION in this module. Please discuss the following questions with your partner and/or other workshop participants. Then use the spaces provided to write down some of the principal ideas that emerge from your discussion.

1. Design an EXPLORATION activity that might be suitable for the very beginning of a high school physics course. Or, design an EXPLORATION activity that might be suitable for introducing the topic of work and energy.

2. Design a CONCEPT INTRODUCTION activity to follow the exploration above.

3. List some APPLICATION activities to follow the example you gave for question #2.

MODULE 6
THE LABORATORY AND SELF-REGULATION

Introduction

Work by Piaget, Bruner, and others studying the development of reasoning in adolescents and adults clearly indicates the need for the learner to (1) actively influence a happening and (2) discuss what he has done, what it means, and how it fits or does not fit with previous ways of thinking. This need gives physics laboratory experiences a key role in the development of reasoning. It also suggests that laboratory work has to be planned carefully if it is to promote the use of formal reasoning patterns. The laboratory should be presented in such a way that students actively consider alternate procedures, debate results, and reflect upon implications.

Objectives

To assist you in identifying and designing laboratory experiences that encourage self-regulation and promote the use of formal reasoning patterns.

Procedure

Join three or four fellow participants and begin by doing the exploration activity. Then continue to work with a partner or the entire group as you read the essay on physics laboratories. An example laboratory exercise is also provided for you to read and discuss. We hope that by working as a group you will be encouraged to compare notes and exchange ideas during this module. Then please proceed to Module 7.

Instructional Materials

1. Exploration

To help you and your partner approach this module in an inventive frame of mind, we ask you to begin with the laboratory investigation introduced on this page. In the module area you will find the following equipment:

clamps
steel strips
small magnets
rulers

Clamp one of the steel strips to a piece of furniture, attach a magnet, and set it swinging.

Now think of some properties that might be affected by the variations, and make measurements to determine quantitative relationships that seem to interest you. You may use objects in your possession, such as a watch, in addition to the ones provided.

Please record your observations and data here. State any conclusions you reach.

After about ten to twenty minutes, join with a group of other workshop participants to discuss some ways in which the above "exploration" might be followed up in a student laboratory exercise.

Please turn to the next page for the first essay.

2. Essay. The Physics Laboratory and Self-Regulation

Suppose you are asked to develop a laboratory exercise on the pendulum for beginning physics students. Rank the following procedures in terms of how you perceive their usefulness in encouraging self-regulation for the students; use 1 for the most effective and 4 for the least effective.

Rank

A. Provide the students with a mass on a string. Indicate the variables of the system and suggest that they verify the square root relationship between the length of the string and the period of oscillation. ____

B. Provide the students with a mass on a string. Supply a list of possible variables of the system (angle of swing, mass, length of string, acceleration of gravity, the period of oscillation, etc.). Supply a list of possible relationships between variables, (the period oscillation is directly proportional to the mass, the period is directly proportional to the length of string, etc.). Ask the students to identify the most accurate relationships between the variables. ____

C. Provide the students with a variety of periodic systems, e.g., a cork floating on water, a baseball bat swinging by a hole in its handle, a clock pendulum, a mass on a string, a uniform metal rod with pivot holes in it. Ask the students to identify variables of these systems and to search for quantitative relationships between the variables. ____

D. Provide the students with a mass on a string. Indicate that for small angles of oscillation there is a relationship between the length of the string and the period of oscillation. Challenge them to discover the relationship based upon their data and then compute the length of string required for a 10 second period. ____

According to our learning cycle model to induce self-regulation, an introductory period of exploration or openness in a laboratory exercise is to be recommended. Hence, procedures B and C are superior to A and D. Furthermore, C is more open and exploratory than B. Procedure C may encourage the student to examine a number of aspects of a swinging object that you may not think are important or interesting, but that appear important to him. It enables the students to begin where they are in their understanding of periodic motion and enlarge their concrete experiences with such systems without having the instructor impose his own reasoning on their activities. Hence, we believe that C is the preferred procedure to use.

Procedure B also provides a good deal of openness while directing the students toward variables determined by the instructor. A variant of this procedure would be a good discovery activity. It tends to focus the activities of the students and make their efforts more efficient if content goals are important. Predictions and expectations in advance of the experiments can be exploited to produce some contradictions in the thinking of the students and start them on self-regulation. Extreme cases not tested directly or concretely can also encourage self-regulation. Hence, we favor procedure D over procedure A. In fact, procedure A has little to recommend it as far as we are concerned.

The social interactions that occur in the laboratory setting are important for starting self-regulation. Testing one's ideas against the ideas of one's peers is a profitable way to spend some time during the laboratory period. Instructor-student dialogues can be very valuable when the instructor asks the student to justify his results. Helping students to become aware of their own thinking is a major function of the instructor if he wishes to encourage his students along the path of self-regulation. Such common thinking tools of physicists as checking the dimensions or units of an answer, making an order of magnitude estimate, and seeing if the answer makes sense at the extreme values of the variables are all aspects of the self-regulation process that can be learned as part of laboratory activities.

At this point it might be helpful to describe how one goes about designing or adapting existing laboratory experiences to fit the EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION cycle. The starting point is the teacher's selection of an interesting phenomenon--an object, event, or situation that (1) students can observe, (2) is amenable to manipulation or description, and (3) leads to the isolation of specific variables. In the exploratory phase of this module, the behavior of a kind of spring oscillator was chosen as the phenomenon. Operation of electric circuits or temperature distributions in a region having a heat source and heat sink are other phenomena that might be investigated.

The steps for successful EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION are these:

1. The teacher isolates an interesting object, event, or situation that can be observed in the laboratory.

2. Students are given an initial period in which they freely explore the object, event, or situation, become familiar with it, raise questions about it, attempt to isolate interesting relationships and variables, and search for patterns or generalizations. This is the EXPLORATION phase.

3. These relationships are highlighted by the teacher or by the students and often given names (e.g., "period" to refer to the time of one complete oscillation, "electric power" in connection with the brightness of a lightbulb, "conduction" and "convection" for the temperature distribution). This is the CONCEPT INTRODUCTION phase.

#1) For the first test, we are varying the weights, while keeping the pull-back and string length constant. The length of time between ten full swings is recorded. The string length is constant to the extent that only the size of the weight causes an increase in the distance to the center of mass.

#2) For the second test, the mass of the object and the string length are held constant, while the pullback is varied. Pullback is made in 10 cm intervals and time is recorded for 10 swing intervals.

#3) Test number three involves changing the length of the supporting string, while holding the mass and pullback constant. The pendulum is allowed to swing for 10 swings and then time recorded.

Data Sheet

Quantitative Values of the Variables of the System (label the columns)					Time required for ten to and fro swings of the obj
TEST 1					
MASS	LENGTH	CONSTANT PULL BACK			
200g	91cm	"			19.2
100g	90.6	"			19.3
50g	89.15	"			19.2
20g	89.5	"			19.1
500g	94cm	"			19.3
TEST 2					
CONSTANT MASS 200g	CONSTANT LENGTH 91cm	PULL BACK			
200g	91cm	10cm			18.9
"	"	20cm			19.1
"	"	30cm			19.2
"	"	40cm			19.5
"	"	50cm			19.7
CONSTANT MASS 200g	LENGTH OF STRING	PULL BACK CONSTANT (30cm)			
"	68 cm	"			16.4
"	61.6 cm	"			15.5
"	52.5 cm	"	OMIT		OMIT
"	73.1 cm	"			17.1
"	84 cm	"			18.3

9-6

If you need additional data space, record your data on the back. If you have finished with your data collection activities, please ask for the inventi page.

4. Students then conduct further investigation of specific variables that have been isolated and seek to establish definite relationships among them. The teacher introduces new materials that permit investigation of the phenomenon in other contexts. For example, after the concept of the "period" has been introduced, investigations of a pendulum, coil spring, or other oscillator would allow for concept reinforcement and permit students to complete the self-regulation process. This is the APPLICATION phase.

What is the positive benefit of beginning a physics lab with the exploratory investigation of some natural phenomenon? In most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in textbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions--questions that must be answered through "real" inquiries.

3. Laboratory on Objects that Swing

In this exercise, we present a laboratory activity arranged according to the learning cycle into EXPLORATION, CONCEPT INTRODUCTION, and CONCEPT APPLICATION. The students were given four pages, one with the title and instructions for exploration (see below), a second page organized as data sheet, a "concept introduction" page, and an "application" page.

Since the last three pages required student recording of data or answering of questions, we are presenting them in reduced format with the data, answers, and work of one pair of students. Please examine these pages and look for evidence of concrete and formal reasoning patterns, self-regulation, and failures to respond to inconsistencies. Then look to our comments on pages 6-9.

SWINGING OBJECTS

Purpose: Examine the properties of objects that swing to and fro when suspended on a string.

Equipment: Objects, string, timer, meter stick, and supports.

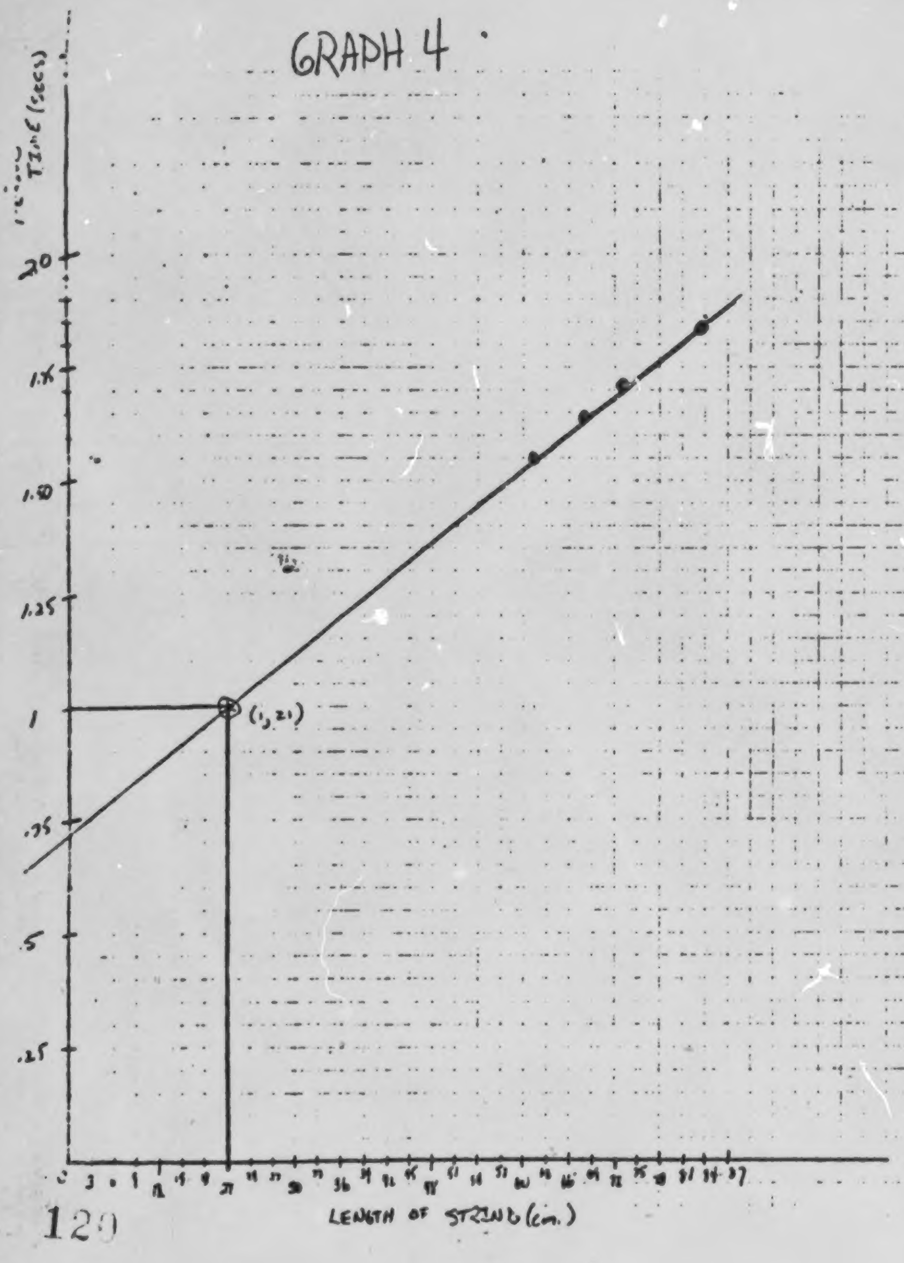
EXPLORATION

Explore the properties of a swing that consists of an object suspended on a string. What are the properties of that system that you can vary? Measure these properties and the period of time required for the object to make ten complete swings to and fro.

When you are satisfied that you have examined all aspects of your system, ask the instructor for the CONCEPT INTRODUCTION.

Please record all the activities you pursue, even ones that may lead to a dead end. You will be evaluated on the completeness of your records as well as the reasonableness of your conclusions.

GRAPH 4



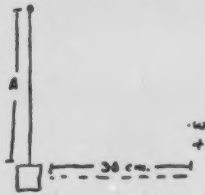
APPLICATION PAGE

Now based upon your previous results either construct or explain in detail how you can construct a system of a swinging object on the string which:

(a) has a period of oscillation of 1.0 second.

A = length of string

21cm. = A



length of string

200g = constant
pullback (angle) = 30cm

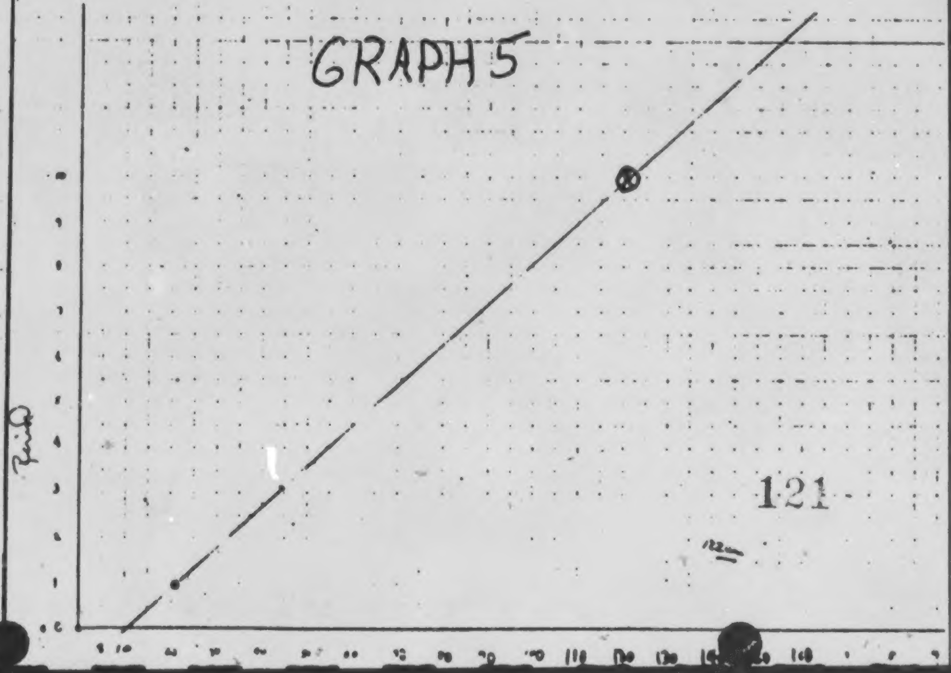
Using test three data and graph we extended the graph (see graph 4) to include the one sec. oscillation interval. This gave us a 21cm.

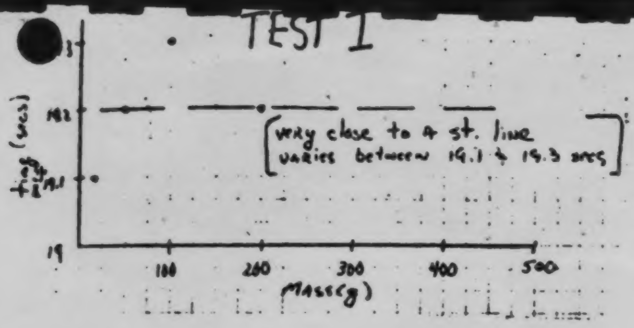
(b) has a period of oscillation of 10.0 seconds.

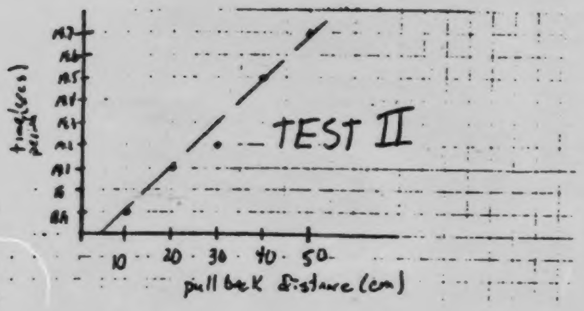
Re-draw graph in opposite direction and go thru same steps as above ANSWER comes out 122cm Common sense indicates this isn't right, but that is our value.

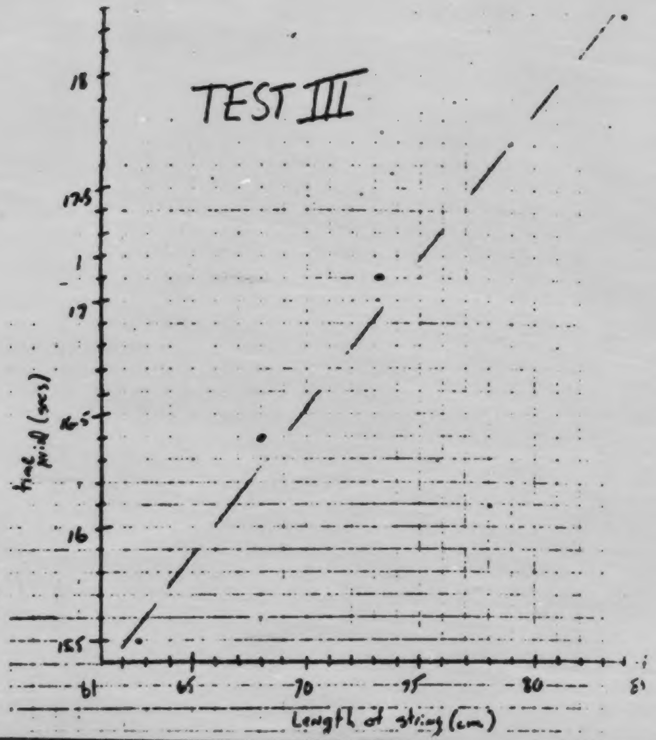
8-9

GRAPH 5









CONCEPT INTRODUCTION

The time required for a swinging object to make one complete trip, to and fro, is called a period.

Which of the properties of your system seemed to have the least effect upon the period of oscillation? It would appear that our test 1 is closest to having the least affect upon the period of oscillation. By varying the mass and keeping a constant pull-back distance of 36.6cm our periods of time varied only from 19.1 to 19.3 secs. So it appears that having a constant pull back distance and changing mass has little affect on period of oscillation.

Which of the properties of your system seemed to have the most effect upon the period of oscillation? Test II has a slight affect upon the period of oscillation, in it we varied the pull-back distance keeping the mass constant. In our test III though we had varied the length of the string keeping the pull back rate constant. In this test our periods of time varied much more, so it would seem that varying the length of the string had the most affect upon the period of time.

What relationships between the period of oscillation and the quantitative values of a property of the system can you identify? In order to express these relationships in a quantitative way you may wish to draw a graph of your data.

Test 1 on graph paper appears to be a constant while tests 2,3 appear to be more like proportions

What conclusions can you reach? State them here:

For test one it appears that little affect upon the period of oscillation is achieved by varying mass with constant pull back [It appears constant], while in the other two parts a proportion seems to result between (period & pullback in 2) & (period and length of string in 3). Quantitative analysis could be calculated in tests 2 & 3

Discuss what you have written on this page with another group of experimenters. List the similarities and differences between your results and theirs here:

Comparing with another group seemed to lead to the same conclusions.

(1.) Keeping constant pull-back with varying mass leads to a constant equation.

(2.) Keeping constant mass and varying the pullback or angle causes a slight difference, but the difference was minimal and would be due to mechanical error.

(3.) Keeping constant mass and ∠ and varying length of string, caused an increase in oscillations per sec

Ask the instructor for the application page.

6-7

Comments on Student Work:

You will have noticed that these students set out systematically to examine the various properties of the system of a swinging object. They carefully isolated variables (mass, amplitude, length), a formal reasoning pattern.

The students' graphical analysis at the end of the experiment, however, does not show the self-regulation one might have expected. Graph 4 shows that a string of zero length would have a 0.70 second period, while Graph 5 leads to the prediction of a 0.0 second period for a string of 10.0 cm length. The inconsistency of these two inferences did not concern the students, though they asserted that their result for the 10 second period contradicts common sense. The use of an analytical tool (plotting points) and applying it to data (drawing a straight line) without self-regulation reveal the concrete reasoning pattern of following instructions step-by-step. Apparently this laboratory activity was not successful in leading these students to self-regulation with respect to data analysis.

Discuss the following items with your partner if they did not come up during your earlier conversation:

1. What other instances of concrete or formal reasoning can you identify in the students' work?

2. What aspects of their work could you use to guide them into self-regulation? Point out the discrepancies or other possible starting points you noticed.

3. Think about some laboratory activities of your students. Do they reflect the learning cycle approach? Do they require the students to follow a "recipe"? How might they help to initiate self-regulation?

Review Questions

Please discuss these questions with your partner after marking your answers.

1. Suppose you are asked to design a laboratory exercise on the topic of Ohm's Law for beginning physics students. Rank the following procedures in terms of how you perceive their effectiveness for encouraging self-regulation on the part of the students. Use 1 for the most effective, 2 for the next, etc. (For our answers, see the bottom of the page.)

	Rank	
	self-regulation	content
A. Provide the students with a 1.5 volt battery, some known resistors, and an ammeter. Ask them to verify the $V = IR$ relationship.	____	____
B. Provide the students with some 1.5 volt batteries, some known resistors, and an ammeter. Supply them with a list of the possible variables of the system: the number of batteries, the number of resistors, the current, the length of connecting lines, etc. Supply a list of possible relationships between the variables: the voltage is directly proportional to the number of resistors in the circuit, the current is proportional to the square root of the resistance, etc. Ask the students to identify the relevant variables and the most appropriate quantitative relationships between them.	____	____
C. Provide the students with a variety of batteries, a variety of resistors including some slide wire type, and a multimeter. Ask them to identify the variables of a circuit and find quantitative relationships between the variables.	____	____
D. Supply the students with a battery, two known resistors, a galvanometer of unknown calibration and several unknown resistors. Ask the students to compute the resistances of the unknown resistors.	____	____
E. Supply the students some lengths of unlabeled metal wires and a resistivity table. Ask them to identify the metals by using Ohm's Law and the definition of resistivity. Provide the necessary apparatus.	____	____

2. Now reread the list and rank the items according to their effectiveness in transmitting content about Ohm's Law. Does this ranking agree with your self-regulation ranking? If not, why do you think that there is a difference?

3. Evaluate the five suggested procedures according to their suitability for EXPLORATION, CONCEPT INTRODUCTION, or APPLICATION activities relating to Ohm's Law.

Answers: For self-regulation we would rank the alternatives B, C, D, E, A; the last three, about whose relative ranking we do not feel very strongly, would be suitable as application activities when self-regulation is in an advanced stage. A would be improved by including a circuit element that did not follow Ohm's Law.

MODULE 6
LABORATORY, FIELD WORK, AND SELF-REGULATION

Introduction

Work by Piaget, Bruner, and others studying the development of reasoning in adolescents and adults clearly indicates the need for two things: (1) the opportunity for the learner to do something with the empirical world, and (2) the opportunity to talk, argue, discuss and otherwise reflect upon what has been done, what it means, and how it fits or does not fit with previous ways of thinking. This gives biology laboratory and field experiences a very key role in the development of thinking and understanding. This also suggests that laboratory and field work, if not presented in such a way that students actively debate results and reflect upon implications and explanations, will do little to enhance abstract thinking abilities. How then can laboratory and field experiences be used most effectively to promote the use of formal reasoning patterns?

Objectives

To assist you in identifying and designing biology laboratory and field work to encourage self-regulation and promote the use of formal reasoning patterns.

Procedure

Join a fellow participant and begin by doing the exploration activity. After discussing the activity continue to work with a partner or a larger group if you wish, then read the essay on laboratory, field work and self-regulation. An example field exercise is also provided for you to read and discuss. We hope that by working as a group you will be encouraged to compare notes and exchange ideas during this module. At its conclusion, please proceed to Module 7.

Instructional Materials

1. Exploration

To help you and your partner approach this module in an inventive frame of mind, we ask that you begin with the laboratory investigation introduced on this page. In the module area you will find the following materials:

- 1 earthworm
- 4 popsicle sticks
- 4 pieces of sponge
- salt water
- 2 eye droppers
- 2 ice cubes
- 2 baggies
- sugar water
- fresh water
- matches

Use the materials to investigate the earth worm's behavior. Identify interesting variables and search for relationships among these variables and the worm's behavior. Please record your observations and data here. State any conclusions you reach.

After about ten to twenty minutes, join with a group of other workshop participants to discuss some ways in which the above "exploration" might be followed up in a student exercise.

Please turn to the next page for the essay on using laboratories and field work for self-regulation.

1. Essay: Laboratories, Field Work, and Self-Regulation

Suppose you are asked to develop a field experience to study the ecology of an intertidal area. Rank the following procedures in terms of how you perceive their effectiveness in promoting self-regulation for your students. Use 1 for most effective and 4 for least effective.

Rank

A. Provide the students with rulers, and run a transect from the upper to lower zone in the intertidal area. Have students measure and record shell sizes of Tegula funebralis snails (a common West Coast snail) found along the transect. Ask them to plot size versus frequency graphs for all the snails measured. ____

B. Provide the students with rulers, quadrats, and a map of the intertidal area, and ask them to measure and record Tegula shell sizes and to determine the density of the snails from three locations in the intertidal area--the lower, middle, and upper zones. Then ask them to search for quantitative relationships among the variables and to explain these relationships in light of other observations and general ecological concepts. ____

C. Explain to the students that interspecific competition affects population characteristics of many species. For example, the snail Tegula funebralis is common in the intertidal area. The older snails (larger ones) are found in the lower zone while the younger snails (smaller ones) live in the upper zone. Tell the students that this is so because their food source (algae) is more abundant in the lower zone; however, the starfish Pisaster that preys upon them, lives in the lower zone. Since the smaller snails are unable to move fast enough to escape the starfish, they must remain in the upper zone. Now have your students go to the intertidal area and collect data to verify that what you have explained is correct. ____

D. Provide the students with rulers, thermometers, identification keys, quadrats, and a map of the intertidal area, and ask them to select an abundant population in the area, identify interesting variables with respect to individual organisms and the population's distribution, and search for quantitative relationships smong these variables. ____

According to the learning cycle model an introductory period of exploration or openness is recommended to induce self-regulation. Hence, procedures B and D are the most likely ways to initiate student questioning and self-regulation. Procedure D may be more effective than B for the students who are already applying formal reasoning patterns. It is more open and allows students to examine interesting phenomena that you may not have anticipated However, procedure D affords little guidance and may not be as effective as the somewhat more structured approach in B for the students who do not yet use formal reasoning patterns. The choice of openness or structure depends on the reasoning abilities of your students and their past experiences with this kind of instruction.

Procedure A provides students with concrete experience. As it is presented, however, it is not liekly to initiate self-regulation in that it is very directed and "cookbook" like. Self-regulation could be initiated if the data plotted raised some questions relative to previous partial understandings.

Procedure C unfortunately is very much like the kind of labs and field work many of us conduct frequently. Since the students already know what the data are supposed to show, no self-regulation and intellectual growth is likely to occur. This is a good way to "turn off" students to biology. Further, it encourages a reliance upon authority rather than on evidence and initiative.

The social interactions that are permitted in the laboratory setting are an important way of starting self-regulation. Testing one's ideas against the ideas of one's peers is a profitable way to spend some time during the laboratory period. Individual contact between the instructor and the student is possible in the laboratory. Such instructor-student dialogues can be very valuable when the instructor asks the student to justify his results. Helping students to learn to think about their own thinking is a major function of the instructor if he wishes to encourage his students along the path of self-regulation.

At this point it might be helpful to analyze how one goes about designing or adapting existing laboratory and field experiences to fit the EXPLORATION, CONCEPT INTRODUCTION,CONCEPT APPLICATION cycle. The starting point for the EXPLORATION,CONCEPT INTRODUCTION.CONCEPT APPLICATION cycle is the teacher's isolation of an interesting phenomenon---an object, event, or situation that students can observe, is amenable to manipulation or description, and leads to the isolation of specific variables.

In the "Exploration" part of this module, the behavior of earthworms and the specific variables of temperature, moisture, and selinity were chosen as the phenomenon and the manipulable variables. The density of Ponderosa pine trees relative to the variables of elevation, rainfall, soil type, and temperature may be another phenomenon and set of variables that could be investigated.

On a field trip, students map the distribution and density of trees over a wide geoegraphical area, measure environmental parameters, search for relationships and attempt to explain these relationships. One further example is the phenomenon of microbial population growth. Specific variables that could be isolated and/or manipulated are nutrients, space, inhibitor chemicals, time, and population size and type.

The steps for successful EXPLORATION,CONCEPT INTRODUCTION,APPLICATION experiences are these:

1. The teacher must isolate an interesting object, event, or situation that can be observed in the laboratory or field.

2. Students are given an initial period in which they freely explore the object, event, or situation, become familiar with it, raise questions about it, attempt to isolate interesting relationships, and relevant variables, and search for patterns or generalizations. This is the EXPLORATION phase. Keep in mind that during this exploration phase "slower" students often get bogged down and need special assistance in getting started and in sustaining interesting avenues of investigation.

3. These relationships are then highlighted by the teacher or by the students and often given names (e.g., "food chain" to refer to guppies eating Daphnia that ate algae, "competitive exclusion" to refer to the elimination of one species of Paramecium for another when raised in the same container). This is the CONCEPT INTRODUCTION phase.

4. Students then conduct further investigations with specific varibles that have been isolated and seek to establish definite relationships among the variables. The teacher introduces new materials that permit investigation of the phenomenon in other contexts. For example,if after the concept of the "ecosystem" has been introduced, field investigations of a forest, pond, seashore, river, or meadow would allow for concept refinement and permit students to complete the self-regulation process. This is the APPLICATION phase.

What is the positive benefit of beginning biology lab and field work with the investigation of some natural phenomenon? In most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in testbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions--questions that must be answered through "real" inquiries.

3. An Example of Student Field Work

The following example of a field investigation is provided to give you an opportunity to see how one pair of students explored a rocky intertidal area, and the types of inventions they arrived at to explain their data. As you read their report look closely for evidences of concrete and formal reasoning patterns. Also look for evidence of self-regulation with respect to the data and various ecological ideas and experiments the students had previously heard or read about. Here is the assignment the students were given.

A Field Trip to the Intertidal Area

Purpose: To examine ecological relationships of intertidal organisms.

Equipment: Rulers, quadrats, thermometers, notebook, pencil, map, identification key.

Procedure: Select a partner with whom you can work. Take 30-50 minutes to explore the various types of organisms that live in the intertidal area. Then choose an abundant population in the area, identify interesting variables with respect to individual organisms of the population and the population's distribution, and search for quantitative relationships among these variables. Keep a record of your data.

Subsequent to the field work, your findings and analyses should be reported and handed in. You will be given three weeks to complete your report.

John R. Brown
Albert Q. Frank
Ecology 472
2-18-68

Tegula Population Study

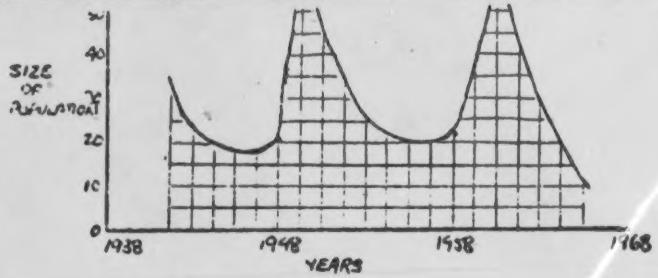
Introduction

The population we selected to study was the *Tegula funebralis* population found at Sunset Bay, Oregon. Quadrats were used to sample the number of snails per quadrat, as well as the size of each snail. We noticed that the smaller snails seemed to be in the upper zones while the larger snails were in the lower zone. Since the snails are so abundant, we decided also to obtain a fairly large sample and plot a graph of its age versus frequency distribution This should give us an indication of the population's state of growth or decline (similar to the salamander population mentioned in the textbook). Our data is on pages 8 and 9.

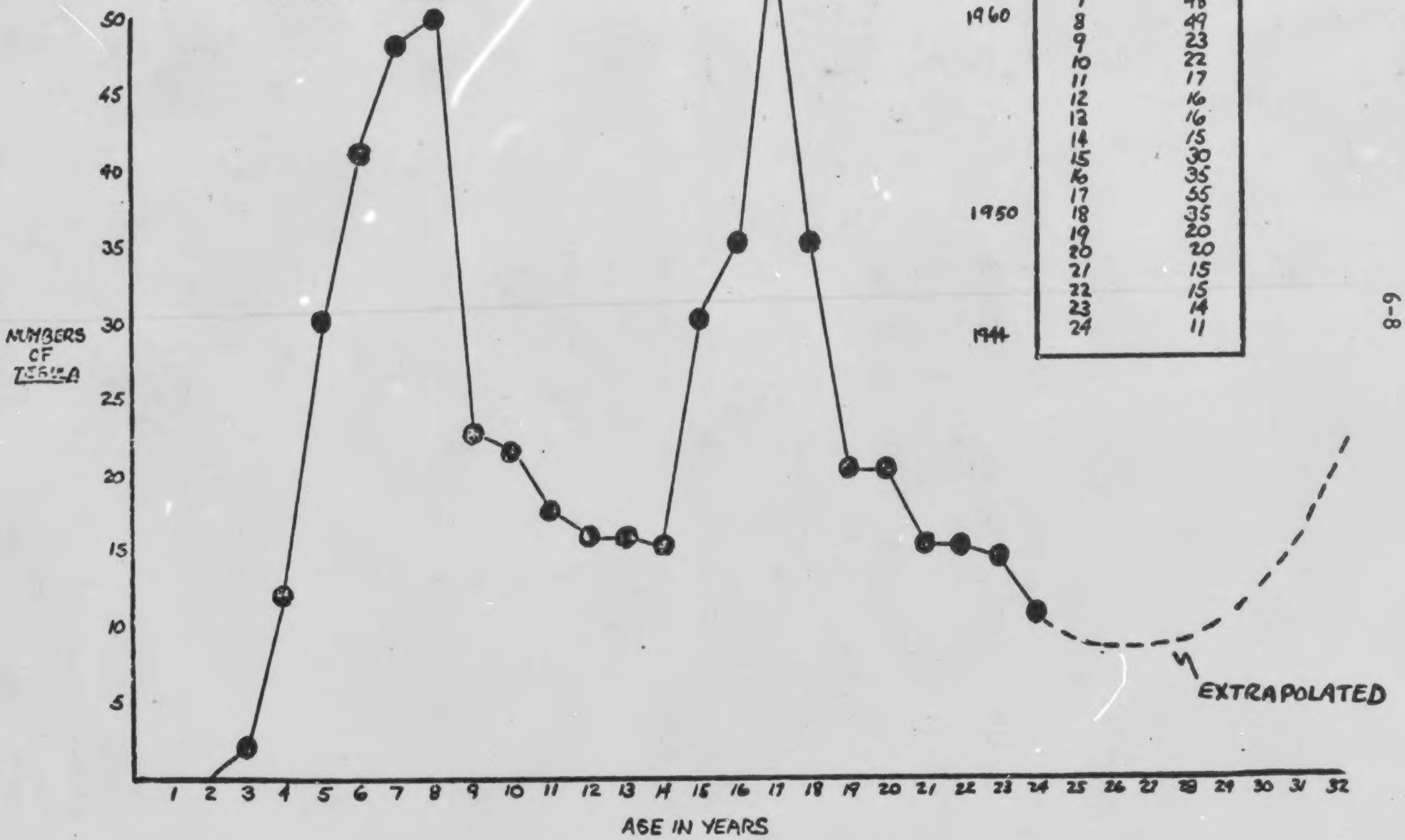
SIZE AND DISTRIBUTION DATA FOR *TEGULA* SUNSET BAY

SIZE (MM)	FREQ.
1.1 - 1.2	1
1.2 - 1.3	0
1.3 - 1.4	1
1.4 - 1.5	1
1.5 - 1.6	1
1.6 - 1.7	10
1.7 - 1.8	30
1.8 - 1.9	30
1.9 - 2.0	41
2.0 - 2.1	48
2.1 - 2.2	49
2.2 - 2.3	35
2.3 - 2.4	33
2.4 - 2.5	41
2.5 - 2.6	44
2.6 - 2.7	38
2.7 - 2.8	29
2.8 - 2.9	22
2.9 - 3.0	15
3.0 - 3.1	10
3.1 - 3.2	8

NUMBER/QUADRAT 80×20 CM	NUMBER OF QUADRATS
0	108
1	51
2	20
3	10
4	14
5	8
6	4
7	2
8	3
9	2
10	1
11	0
12	1
13	0
14	1
15	0
16	0
17	1
21	1
[illegible]	1
[illegible]	1
[illegible]	1



DENSITIES OF *TEGULA*



	AGE	FREQ.
1968	1	0
	2	0
	3	2
	4	12
	5	30
	6	41
	7	48
1960	8	49
	9	23
	10	22
	11	17
	12	16
	13	16
	14	15
	15	30
	16	35
	17	55
1950	18	35
	19	20
	20	20
	21	15
	22	15
	23	14
1944	24	11

8-9

AGE DISTRIBUTION OF *TEGULA*

Conclusions and Discussion of Tegula results

The graphs on page 9 seem to show that the Tegula population is increasing and decreasing approximately every eight to ten years. The growth period approaches an exponental growth, characteristic of organisms in an unlimited environment and then it declines suddenly.

These crashes could be attributed to severe environmental conditions each 8 to 10 years, but the oscillations appear to be truly cyclic so this most unlikely. (Sunspots could also be considered an unlikely cause!)

A density dependent mechanism could be responsible. As the population grows too large, some density dependent factor acts to reduce the population. If the population falls below a certain level, the dencity dependent processes fade and the population builds up. Such a system would result in regular oscillations, however, in our case the oscillations appear to be too great for this model to hold.

Intraspecific competition in the Tegula population for a limited resource could be cited as a cause of the oscillations. This could result in rather violent oscillations

A more likely cause of the oscillations is interspecific competition between some predator e.g. the starfish, and the prey -- Tegula. A model for this type of competition states that as the predator population increases, they consume a larger number of prey until the prey population begins to decline As the numbers of prey decline, the predators have less and less food so their population declines. In time the number of predators is so small due to starvation that the prey are left free to increase in numbers and so on. This cycle may continue indefinately.

It seems likely that the starfish can capture the smaller snails more easily than the larger ones. The larger the snail the faster it can move to escape the predator.

To show this hypothesis correct or incorrect, information about the age distribution of the predator of Tegula would be needed. If oscillations occurred that coincided with the ones for Tegula then the hypothesis would be supported. It is clear that additional information about the snails life cycle as well as its daily activities would be needed as a starting point for additional research.

One final alternative, that perhaps is the best explanation, is that the snails and their food source are in a cyclic relation. The snails food supply is depleted when the snail population is up, therefore, a fall in population results with a subsequent rise in food supply. This idea also has its drawbacks. No obvious answer is available without additional research.

4. Comments and Questions About Student Work

Certainly the field activity should be considered part of the exploration phase of this investigation. We also consider lectures and textbook readings about ecological concepts as part of the exploration phase in this case. These are explorations since the instructor was very perceptive and allowed the students a good deal of time to integrate the abstract readings and lectures with the concrete experiences prior to requesting some final product. This integration process is a fundamental part of self-regulation.

1. What evidences did you find of concrete and formal reasoning in the students work?

2. What are some of the student's inventions following their explorations and data gathering?

3. Do you think the students have reached a state of equilibrium in their thinking about the oscillations in the snail population size?

4. What sort of discovery experiences do the students seem to ask for at the end of their report?

Review Questions

Please respond to the following questions and then discuss your answers with your partner.

1. Suppose you are asked to develop a laboratory to study the heart of Daphnia. Rank the following procedures in terms of how you perceive their effectiveness in promoting self-regulation for your students. Use 1 for most effective and 4 for least effective.

	Rank	
	Self-Regulation	Content
A. Provide the students with live Daphnia, thermometers, depression slides, and compound microscopes. Have the students count the number of heartbeats per minute of the Daphnia at three different temperatures; 5, 20 and 35 degrees C. Ask them to plot the number of heartbeats versus the temperature on a sheet of graph paper.	____	____
B. Provide the students with live Daphnia, thermometers, depression slides, and compound microscopes, and ask them to find the number of heartbeats per minute. Then ask them to find out if different temperatures influence the rate of heartbeat and to explain how variables could account for the differences observed.	____	____
C. Explain to the students that temperature has a general effect on the metabolism of invertebrates. Higher temperature means a higher rate and lower temperature slows down metabolic activity. One rule states that metabolic rate doubles for every 10 degrees increase in temperature. A cold-blooded animal like the Daphnia is directly influenced by the environmental temperature. Now have your students go to the laboratory and use live Daphnia to verify that what you have explained is correct.	____	____
D. Provide students with live Daphnia, a hot plate, dexedrin solution, 5% solution of alcohol, a light source, rulers, thermometers, slides, pH paper, balances, graph paper, microscopes, a stirring device and ice cubes. Ask them to investigate the influence of environmental changes on the heartbeat of Daphnia, and to search for quantitative relationships among the variables.	____	____

2. Now reread the list and rank the items according to their effectiveness in transmitting content about physiology. Does this ranking agree with your self-regulation ranking? If not, why do you think that there is a difference?

3. Evaluate the four suggested procedures according to their suitability for CONCEPT INTRODUCTION or APPLICATION activities relating to physiology.

Our answer to # 1:

We would rank the alternatives D, B, A, C. Alternative C would provide a good CONCEPT INTRODUCTION lesson following exploratory activities suggested in alternatives D, B or A. Alternative A or B could serve as an application activity about the concept of stimulus-response following explorations suggested in D.

MODULE 6
THE LABORATORY AND SELF-REGULATION

Introduction

Work by Piaget, Bruner, and others studying the development of reasoning in adolescents and adults clearly indicates the need for two things: (1) the opportunity for the learner to do something with the empirical world, and (2) the opportunity to talk, argue, discuss and otherwise reflect upon what has been done, what it means, and how it fits or does not fit with previous ways of thinking. This gives general science laboratory experiences a key role in the development of thinking and understanding. This also suggests that laboratory work, if not presented in such a way that students actively debate results and reflect upon implications and explanations, will do little to enhance abstract thinking abilities. How then can laboratory experiences be used most effectively to promote the use of formal reasoning patterns?

Objectives

To assist you in identifying and designing general science laboratories that encourage self-regulation and promote the use of formal reasoning patterns.

Procedure

Join three fellow participants and begin by doing the exploration activity. After discussing the activity continue to work with a partner or the entire group of three if you wish, then read the essay on laboratories. An example laboratory exercise is also provided for you to read and discuss. We hope that by working as a group you will be encouraged to compare notes and exchange ideas during this module. At its conclusion, please proceed to Module 7.

Instructional Materials

1. Exploration

To help you and your partners approach this module in an inventive frame of mind, we ask you to begin with the laboratory investigation introduced on this page. In the module area you will find the following equipment: clamps, steel strips, rulers, and small magnets. Clamp one of the steel strips to a piece of furniture, attach a magnet, and set it swinging.

Now think of some properties that might be affected by the variations, and make measurements to determine quantitative relationships that seem to interest you. You may use objects in your possession, such as a watch, in addition to the ones provided.

Please record your observations and data here. State any conclusions you reach.

After about ten to twenty minutes, discuss with your group members some ways in which the above "exploration" might be followed up in a student laboratory exercise.

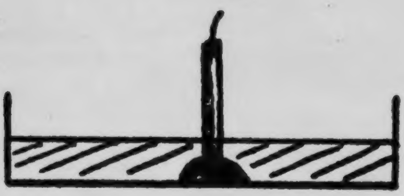
Please turn to the next page for the first essay.

2. Essay: The General Science Laboratory and Self-Regulation

Suppose you are asked to develop a laboratory activity to study the concept of air pressure. Rank the following procedures in terms of how you perceive their effectiveness in initiating self-regulation for your students. Use 1 for most effective and 4 for least effective.

Rank

A. Provide students with plastic boxes, cylinders (open at one end), jars and glasses (of various sizes and shapes), matches, water, a ruler, candles, a block of wood, and clay. Have them set up the materials as shown in the figure below. Then light the candle, put a container over the candle and observe what happens. Suggest that they repeat the experiment several times in several ways, record observations, and attempt to explain what happens.



B. Provide students with plastic boxes, a cylinder (open at one end), matches, water, a candle, and a piece of clay. Have them observe the effect of air pressure by putting the cylinder over the burning candle and observing the candle go out and the water rise into the cylinder. Explain that the water rose because: (1) the heated air expanded and escaped out the bottom of the cylinder, (2) the air cooled and contracted, and (3) this resulted in less air pressure inside the cylinder than outside, therefore, the water rose into the cylinder until the pressures were equal.

C. Provide students with plastic boxes, cylinders (open at one end), jars and glasses (of various sizes and shapes), matches, water, a ruler, candles, a block of wood, and clay. Have them set up the experiment as described above, and follow this procedure: (1) use one candle and measure water rise, (2) repeat using two, then three, them four candles and measure water rise--record all data. Note the bubbles escaping from the bottom of the cylinder. Repeat again, this time place the candle in the clay on the block of wood. Float the block of wood on the water, light the candle, and place the cylinder over the candle and block of wood. Note the water rise after the candle goes out. Attempt to explain what happens.

D. Provide students with a flat-sided one gallon can that has a screw cap. (1) Place the can on a hot plate and remove the screw cap, (2) place two tablespoonful of water in the can and boil for several minutes with the screw cap off the top of the can, (3) remove the can from the heat and stopper the can immediately, and (4) observe and explain what happens when the steam cools.

According to the learning cycle model an introductory period of exploration or openness is recommended to induce self-regulation. Hence, procedure A is superior to procedures B, C, and D. Procedure A is extremely good in that it provides students with a rich variety of approaches by the students. It should be pointed out, however, that many students who may be unaccustomed to EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION laboratory activities may bog down after a short while. Still others may mistakenly believe they have solved the mystery of the rising water and also bog down. You, the teacher, must be alert to these students and subtly suggest variations to their experiments that will provide data to provoke further exploration.

Although procedure C appears very similar to procedure A, it differs in one significant way. The explicitness of the procedure eliminates much of the student exploration. This explicit "cookbook" approach short circuits student initiative and thinking and therefore prohibits self-regulation. Two of the observations mentioned in this procedure (the bubbles and the water rising after the candle goes out) as well as the data gathered by varying the number of candles are crucial pieces of evidence for the "correct" explanation for the rising water. However, this evidence should not be given to the students. It should be sought and gathered by them or at least they should be subtly directed to this evidence.

Procedure B involves concrete experience which is important from the Piagetian perspective. However, since the teacher "gives" the explanation to the students, no critical thinking or self-regulation is likely to take place. Unfortunately, this type of procedure is far too common in most classrooms. Rather than providing experiences and encouraging continued investigation and student inquiry, teachers are often too concerned that students obtain the "right" answer and that they obtain it quickly so that more material can be covered.

Procedure D certainly will provide an interesting phenomenon that could provoke student thought. Its major drawback, however, is that very few directions are left open to the students to further explore with the materials. Most likely after the experiment they would either be asked to read about air pressure in their text or simply be told about it by their teacher. Further, the procedure is very directive as now stated. Little exploration or self-regulation is likely to occur with this approach.

The social interactions that are permitted in the laboratory setting are an important way of starting self-regulation. Testing one's ideas against the ideas of one's peers is a profitable way to spend some time during the laboratory period. Individual contact between the instructor and the student is possible in the laboratroy. Such instructor-student dialogues can be very valuable when the instructor asks the student to justify his results. Helping students to learn to think about their own thinking is a major function of the instructor if he wishes to encourage his students along the path of self-regulation.

At this point it might be helpful to describe how one goes about designing or adapting existing laboratories to fit the EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION cycle. The starting point is the teacher's isolation of an interesting phenomenon--an object, event, or situation that (1) students can observe, (2) is amenable to manipulation or description, and (3) leads to the isolation of specific variables. In the exploratory phase of this module, the behavior of a kind of spring oscillator was chosen as the phenomenon. The reaction of mealworms to environmental variations in temperature, light, and moisture are other phenomena that might be investigated.

The steps for successful EXPLORATION, CONCEPT INTRODUCTION. CONCEPT APPLICATION are these:

1. The teacher must isolate an interesting object, event, or situation that can be observed in the laboratory or field.

2. Students are given an initial period in which they freely explore the object, event, or situation, become familiar with it, raise questions about it, attempt to isolate interesting relationships and relevant variables, and search for patterns or generalizations. This is the EXPLORATION phase. Keep in mind tha during this exploration phase "slower" students often get bogged down and need special assistance in getting started and in sustaining interesting avenues of investigation.

3. These relationships are then highlighted by the teacher or by the students and often given names (e.g., "food chain" to refer to guppies eating Daphnia that ate algae, "air pressure: to refer to the force that pushes the water up into the cylinder). This is the CONCEPT INTRODUCTION phase.

4. Students then conduct further investigations with specific variables that have been isolated and seek to establish definite relationships among the variables. The teacher introduces new materials that permit investigation of the phenomenon in other contexts. For exampke, if the concept of the "ecosystem" has been introduced subsequent to explorations of a laboratory aquarium, then field investiagtions of a forest, pond, seashore, river, or meadow would allow for concept reinforcement, refinement, and enlargement which permits students to complete the self-regulation process. This is the CONCEPT APPLICATION phase.

What is the positive benefit of beginning lab work with the exploratory investigation of some natural phenomenon? In most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in textbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions--questions that must be answered through "real" inquiries.

3. An Example Laboratory on Air Pressure

The following student laboratory report is provided to give you an opportunity to see how one pair of students explored the candle burning materials. We also have provided a report submitted by another pair of students that includes notes on all three phases of the learning cycle. As you read this report notice the phases of EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION. Try to identify concrete and formal reasoning patterns. Also look for evidence of self-regulation with respect to the data and the various ideas advanced by the students.

CANDLE BURNING LABORATORY

Purpose: To observe, manipulate, analyze, and attempt to explain a physical phenomenon.

Equipment: A pan, a cylinder (open at one end), jars and glasses (of various sizes and shapes), matches, water, a ruler, candles, a block of wood, clay.

Procedure: Select a partner with whom you can work and obtain the materials. Pour some water into the pan. Stand a candle in the pan using the clay for support. Light the candle and put the cylinder over the candle so that is covers the candle and sits in the water. Observe what happens. Take the rest of the laboratory period to perform the experiment in a variety of ways. Remember to record your data. What questions are raised? Attempt to answer these questions. Seek data to support your answers. Discuss your ideas and data with other students and the teacher.

LORY BROWN
DEBBIE
MARTIN

EXPLORATION

Two variables that can be investigated are the amount of water in the pan and the number of lighted candles. Can you think of others? List them and make a check beside the variables whose effect you have investigated.

Variables of the system: What causes the water to RISE?
Number of candles used, -length ✓
Beaker instead of test tube, JAR. ✓
Amount of water in the tray. ✓ (SIZE ALSO) ✓

In the space provided record what you do and all of your observations. What questions are raised? Can you think of answers for these questions? If so seek data to support your ideas. Discuss your ideas and data with other students and the teacher.

DATA TABLE

Observations (list them)

1. Water rises 2. The bigger the
beaker the longer the candle burns.
3. More candles = higher water 4. Candle
on wood rises after it goes out.
5. More candles = higher flame
6. Wet beaker turns black. 7 Bubbles came
out of bottem of beaker.
8. Clay came off bottem (some times)

Water rised two cem. with 1 candle.
" " 3½ cem with 2 ". med. beaker
With Wood water rose 1½ but rose after candle
wento out.

With a tall container it takes alonger per. of time
before it goes out
WATER RISED 3½ cent. with 3 candles
" " small beaker. 2½, 3 candle
5 candles, large beaker, 4½ cent.
6 candles, large beaker 4½ cent. candles
went out almost one by one beginning
with biggest

Brian Hill
Tammy Carlson
November 13, 1976

Candle Burning Report

When we put the cylinder over the burning candle we found out that the candle went out. After it went out the water rose into the cylinder.

The question that we had was what caused the water to go into the cylinder.

Here is a list of our observations.

1. smoke was inside the cylinder
2. the faster the cylinder was put on the candle the higher the water went
3. some bubbles came out of the bottom of the cylinder
4. the more candles the higher the water rose
5. different sizes of jars and glasses made the water rise different amounts.

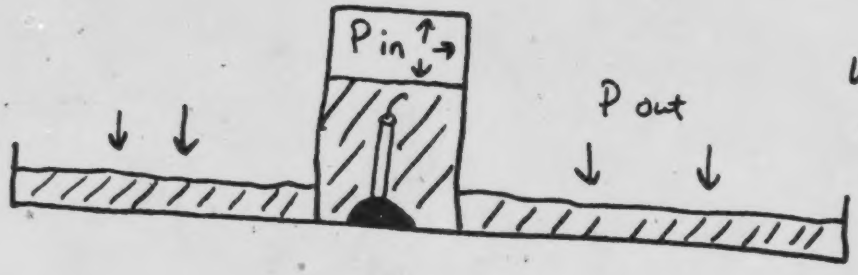
At first we decided the water rose because the candle burned up the oxygen. The reason the candle went out was because the oxygen was used up. We did the experiment a lot of different ways and made some observations that did not make cents.

After a discussion in which almost all of us agreed that the water was sucked up because the candle used up the oxygen, Mr. Kimball told us to put a candle on a block of wood floating on the water and try again.

We found out that the water still went up after the candle burned out.

We changed our minds when Janet said it was because the candle heated the air. The heated air went out of the cylinder. When the candle went out the air got cooler and began to shrink. This is what Janet and Mr. Kimball said.

The air pressure sucked the water in since the air inside was less. The picture on the board was like this.



When $P_{in} = P_{out}$ the water stops going up.

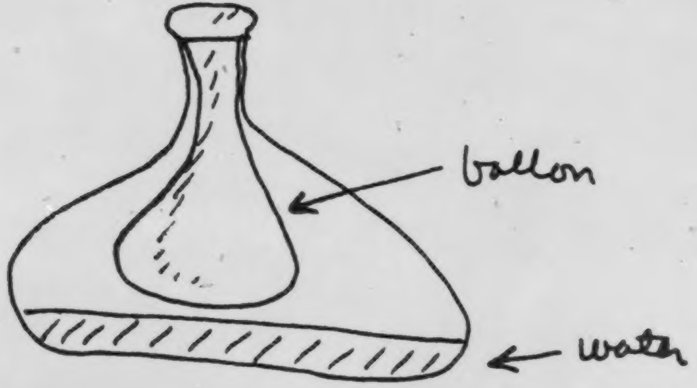
After Mr. Kimball told us about air pressure he told us to do some more things. This is what we did that he suggested.

1. We made a pealed egg pop into a bottle by burning paper in the bottle to heat up the air. We put the pealed egg on top of the bottle. When the air cooled it made the egg pops into the bottle.

2. We stuck two plungers togather and tried to pull them apart. This was hard because of air pressure.

3. We put an upside down cup in a pan of water. We had to use a syring and a plastic tube to fill the cup up with water without turning the cup over.

4. We had a ballon, a big candle, a bunsen burner, a flask, and we had to find out how to get the ballon in the flask like this.



Comments on Student Report:

Clearly the initial activity of setting up the experiment, repeating it a number of times and varying a number of experimental parameters serves as EXPLORATION. The students' explanation (oxygen depletion, suction) of why the water rose into the cylinder required CONCEPT INTRODUCTION. Notice that they came to a concept that was incompatible with a number of pieces of data, i.e., the bubbles, the more candles the higher the water, and the fact that the water continued to rise after the candle went out. Once another student came up with a new explanation that was consistent with the data, the original idea was abandoned. Students may not always come up with this idea; therefore, the key concept must at times be supplied by the teacher.

Notice that the explanation involving the concept of air pressure was not fully understood by these students. They continued to think of the water as being sucked rather than being pushed. Some misunderstanding of this sort is not surprising. The idea of sucking is far more consistent with concrete experience than is the image of differential partial pressures created by unequal numbers of randomly moving molecules.

The final page of the student report describes four CONCEPT APPLICATION activities. These provide the students with additional experiences, challenges, and opportunities to think about the idea of air pressure and how to apply it to explain related phenomena and solve new problems. This phase of the learning cycle is crucial for it allows students to engage in the process of self-regulation until it reaches its natural end point - in this case, understanding of the concept of air pressure. This student report was not complete enough to enable us to know to what extent these students had self-regulated successfully.

Discuss the following items with your partner if they did not come up in an earlier conversation.

1. Does the concept of air pressure require formal reasoning? If so, why? If not, why not?

2. Do you find evidence of concrete and formal reasoning being used by these students?

3. What would you do if your students were convinced that the water rose because the oxygen was burned up? Do you see anything wrong with just telling the students that this explanation is wrong?

4. Think of some laboratory activities you do with your students. Do they reflect the learning cycle approach? Do they require the students to follow a "recipe"? How might they be changed to help initiate self-regualtion?

Review Questions

Please respond to the following questions and then discuss your answers with your partner.

1. Suppose you are asked to develop a laboratory to study the heartbeat of Daphnia. Rank the following procedures in terms of how your perceive their effectiveness in promoting self-regulation for your students. Use 1 for most effective and 4 for least effective.

	Rank	
	Self-Regulation	Content
A. Provide the students with live Daphnia, thermometers, depression slides, and compound microscopes. Have the students count the number of heartbeats per minute of the Daphnia at three different temperatures; 5, 20, and 35 degrees C. Ask them to plot the number of heartbeats versus the temperature on a sheet of graph paper.	___	___
B. Provide the students with live Daphnia, thermometers, depression slides, and compound microscopes, and ask them to find the number of heartbeats per minute. Then ask them to find out if different temperatures influence the rate of heartbeat and to explain how variables could account for the differences observed.	___	___
C. Explain to the students that temperature has a general effect on the metabolism of invertebrates. High temperature means a higher rate and lower temperature slows down metabolic activity. One rule of thumb states that metabolic rate doubles for every 10 degrees increase in temperature. A cold-blooded animal like the Daphnia is directly influenced by the environmental temperature. Now have your students go to the laboratory and use live Daphnia to verify that what you have explained is correct.	___	___
D. Provide students with live Daphnia, a hot plate, dexedrin solution, 5% solution of alcohol, a light source, rulers, thermometers, slides, pH paper, balances, graph paper, microscopes, a stirring device, and ice cubes. Ask them to investigate the influence of environmental changes on the heartbeat of Daphnia, and to search for quantitative relationships among the variables.	___	___

2. Now reread the list and rank the items according to their effectiveness in transmitting content about physiology. Does this ranking agree with your self-regulation ranking? If not, why do you think that there is a difference?

3. Evaluate the four suggested procedures according to their suitability for CONCEPT INTRODUCTION or APPLICATION activities relating to physiology.

Our answer to #1:

We would rank the alternatives D, B, A, and C. Alternative C would provide a good INTRODUCTION lesson following EXPLORATION activities suggested in alternatives D, B or A. Alternative A or B could serve as an APPLICATION activity for the concept of stimulus response.

MODULE 6
LABORATORY, FIELD WORK, AND SELF-REGULATION

Introduction

Work by Piaget, Bruner, and others studying the development of reasoning in adolescents and adults clearly indicates the need for two things: (1) the opportunity for the learner to do something with the empirical world, and (2) the opportunity to talk, argue, discuss, and otherwise reflect upon what has been done, what it means, and how it fits or does not fit with previous ways of thinking. This gives earth science laboratory and field experiences a key role in the development of thinking and understanding. This also suggests that laboratory and field work, if not presented in such a way that students actively debate results and reflect upon implications and explanations, will do little to enhance abstract thinking abilities. How then can laboratory and field experiences be used most effectively to promote the use of formal reasoning patterns?

Objectives

To assist you in identifying and designing laboratory and field experiences that encourage self-regulation and promote the use of formal reasoning patterns.

Procedure

Join three fellow participants and begin by doing the exploration activity. After discussing the activities continue to work with a partner or the entire group of three if you wish, then read the essay on laboratories. An example laboratory exercise is also provided for you to read and discuss. We hope that by working as a group you will be encouraged to compare notes and exchange ideas during this module. Then please proceed to Module 7.

Instructional Materials

1. Exploration

To help you and your partner approach this module in an inventive frame of mind, we ask you to begin with the laboratory investigation introduced on this page. In the module area you will find the following equipment:

- test tubes
- tubing
- vinegar
- ruler
- stoppers
- steel wool
- water with food coloring

Rinse some steel wool in vinegar, squeeze it, stuff it into a test tube, and close the test tube with a one-hole stopper fitted with a piece of tubing. Dip the end of the tube into colored water and observe the changes.

Now think of the chemical changes that may be occurring and of the conditions that might affect the process. Make measurements to determine quantitative relationships that seem to interest you. You may use objects in your possession, such as a watch, in addition to the ones provided.

Please record your observations and data here. State any conclusions you reach.

After about ten to twenty minutes, join with a group of other workshop participants to discuss some ways in which the above "exploration" might be followed up in a student laboratory exercise.

Please turn to the next page for the first essay.

2. Essay: Earth Science Laboratories, Field Work and Self-Regulation

Suppose you are asked to develop a laboratory activity to study the process of stream development. Rank the following procedures in terms of how you perceive their effectiveness in initiating self-regulation for your students. Use 1 for most effective and 4 for least effective.

Rank

A. Provide your students with a stream table, sand, water, buckets, siphon tubing and clamps. Begin a siphon flow in one stream table and adjust it with a clamp. Ask the students to set up other stream tables but suggest they experiment with them by making observations on their streams for several minutes, then changing them in some way and making more observations, and finally, attempting to explain how the changes they made affected their streams. ____

B. Provide students with a stream table, sand, water, buckets, siphon tubing and clamps. Have the students set up their stream flow with the clamp to between 5 and 10 ml of water per second (they may test this rate of flow using a graduate). Have them observe the development of the stream in their stream tables for the next 25 minutes. Move about the groups of students during this time pointing out the following phenomena: (1) headward erosion, (2) bank slumping, (3) change in rate of flow along the stream's course, (4) differential movement of particles of different sizes and/or densities, (5) deposition of sediment, and (6) changes in the stream's course at the mouth. ____

C. Provide students with a stream table, sand, water, buckets, siphon tubing and clamps. Have them set up stream tables and adjust their flow rates as described in B. above, and then follow this procedure: (1) record all observations you can make on the development of the stream's channel for 10 minutes, (2) raise the higher end of your stream table 3 cm. and record all observations for 10 minutes more. Note the changes in rate of particles movement and the deepening of the channel, and (3) increase the rate of flow of your stream from 5-10 ml of water per second to 20-25 ml per second. Note the increase in the rate of delta development. Explain how the factors of stream gradient and stream volume affect stream development. ____

D. Provide the students with stream tables, sand, water, buckets, siphon tubing, clamps, metric rules, balances and waxed paper. Divide students into 6 groups, each being directed to set up their stream tables with a piece of waxed paper laid on the bottom of the stream table at the contact between the sand and the reservoir so that sediment from the stream will collect on it. Provide each group with the following procedures:

group 1: set stream table head 2 cm higher than base, water flow 10 ml/sec.
group 2: set stream table head 4 cm higher than base, water flow 10 ml/sec.
group 3: set stream table head 6 cm higher than base, water flow 10 ml/sec.
group 4: set stream table head 2 cm higher than base, water flow 20 ml/sec.
group 5: set stream table head 2 cm higher than base, water flow 30 ml/sec.
group 6: set stream table head 4 cm higher than base water flow 20 ml/sec.

All groups make observations under these conditions for 15 minutes, then stop, carefully remove all sand on the waxed paper, and determine the amount with the balance. Tabulate and graph results on the board and discuss with the class.

According to the learning cycle model, an introductory period of exploration or openness is recommended to induce self-regulation. Hence procedure A is superior to the others. This procedure allows a wide variety of approaches to the investigation of stream development.

Keep in mind, however, that many students who are unaccustomed to EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION laboratory activities may at first have difficulty generating approaches to investigating the behavior of their stream. They may set up the materials, watch them for several minutes, and feel that they have made all the observations they require to explain how streams develop. It is your responsibility to be alert to these student behaviors and to ask questions and subtly suggest variations to their investigations which could provide more data and hence provoke further investigation.

Procedures C and D both appear to be similar to procedure A. C, however, is too explicit in terms of student directions and will focus student attention only on stream gradient and volume as factors which influence stream development. This is not only misleading, but also blocks student initiative and thinking. The additional focussing of student attention to rate of particle movement, channel deepening, and rate of delta development is really redundant. These notes generally serve only as a means of assuring the instructor that the students will "make the right observations and conclusions." They further restrict student investigation of other phenomena occurring in the stream table.

Procedure D has the appearance of providing the entire class with a collective means of investigating the variables of gradient and flow rate, promises to allow for the graphic display of data that will lead to conclusion of the activity. While attempts to quantify whenever possible are laudable, especially in the earth sciences, this procedure will inhibit student exploration to a greater extent than C. Procedure D will focus student attention upon too limited an area of inquiry to provide self-regulation. In addition, it is unlikely that the students will be able to control all the variables involved in the stream table to the extent that any meaningful data will be collected.

Certainly more social interaction is permitted in the laboratory setting than in many other classroom organizations, and this is an important way to begin self-regulation. Testing and comparing your ideas with those of your classmates is a desirable expenditure of laboratory time.

Also, more individual contact between student and instructor is possible in the laboratory and such dialogue is quite valuable. When students are asked to explain or justify their results, the instructor has an excellent opportunity to diagnose the extent of critical thinking and the process skill development of the student. He is then in a much better position to provide individual help. Helping a student to learn to reflect upon his own thinking is a major function of the instructor who wishes to encourage self-regulation.

At this point it might be helpful to analyze how one goes about designing or adapting existing laboratories to fit the EXPLORATION, CONCEPT INTRODUCTION CONCEPT APPLICATION cycle. The stepping off point is the teacher's isolation of an interesting phenomenon--an object, event, or situation that students can observe, is amenable to manipulation or description, and leads to the isolation of specific variables. In the exploratory phase of this module, the behavior of steel wool and vinegar in air was chosen as the phenomenon. The distribution of various size particles of sand and pebbles along a beach relative to a nearby river, a jetty, offshore stacks or a reef could be a phenomenon chosen to investigate on a field trip.

The steps for successful EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION experiences are these:

1. The teacher must isolate an interesting object, event, or situation that can be observed in the laboratory or field.

2. Students are given an initial period in which they freely explore the object, event, or situation, become familiar with it, raise questions about it, attempt to isolate interesting relationships and relevant variables, and search for patterns or generalizations. This is the EXPLORATION phase. Keep in mind that during this exploration phase "slower" students often get bogged down and need special assistance in getting started and in sustaining interesting avenues of investigation.

3. These relationships are then highlighted by the teacher or by the students and often given names (e.g., headward erosion and bank slumping to refer to phenomena studied with the stream tables, convection to refer to the movement of liquid in a container heated at one end). This is the CONCEPT INTRODUCTION phase.

4. Students then conduct further investigations with specific variables that have been isolated and seek to establish definite relationships among the variables. The teacher introduces new materials that permit investigation of the phenomenon in other contexts. For example, if the concept of convection was introduced relative to the motion of water currents, investigations of atmospheric circulation patterns would allow for concept reinforcement, refinement, and enlargement and permit students to complete the self-regulation process. This is the APPLICATION phase.

What is the positive benefit of beginning lab work with the investigation of some natural phenomenon? In most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in textbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions--questions that must be answered through "real" inquiries.

3. An Example Laboratory on Stream Development

The following student laboratory report is provided to give you an opportunity to see how a group of four students investigated the stream table materials. As you read their report, notice the phases of CONCEPT INTRODUCTION and CONCEPT APPLICATION. Also look for evidence of self-regulation with respect to the data and the various ideas advanced by the students.

INVESTIGATING STREAM DEVELOPMENT

Purpose: To observe, model, analyze, and attempt to explain some phenomena associated with stream development.

Equipment: A stream table, sand, water, four buckets, siphon tubing, and clamps, plus any other materials available in the classroom.

Procedure: Form groups of four and set up the materials similar to the demonstration materials at the front of the room. Begin a siphon flow and adjust it with a clamp. For several minutes observe the stream that forms. Record all the observations that you make. Think about how you might change your stream table setup. Make these changes and again make observations. Record all new observations. What questions do the two sets of observations raise? Attempt to answer these questions based upon the data that you collect. Feel free to discuss your ideas and data with your teacher and with other students.

Dec 18, 1975

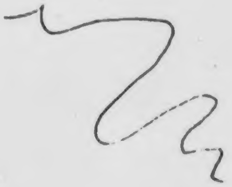
Tanya Barnon
Fred Johnson
Cindy Cronk
Karl Smith

Stream Development Report

We set up our stream table and got it going with the syphon tubing. We just let a trickle of water into the reservoir so that the stream would run kind of like a real stream. We made a bunch of observations on what happened to our stream for 5 minutes: They are listed as follows:

1. The water carries small sand grains easier than large ones
2. The large grains (some of them) roll along the stream bed.
3. Real small particles are carried way out into our lake at the end of the stream table.
4. The sand grains stop when they get to the lake and pile up.
5. The mouth of the stream is in different places at different times
6. Black stuff seems to collect on the bottom of the stream
7. When you tap the sand with your finger the surface of the sand gets real wet.

We decided to make our stream more like Brush Creek near school so we flattened out the old stream and made a new pathe for the stream which was real curvy like this -



We made more observations for almost 10 minutes

1. The water seems to run slower than in our first stream.

2 The stream banks wear away on the outside of the curve of the stream.

3. Less sand seems to get to the stream mouth than with the first stream

4 The water runs fast around the corners but slows down when the stream is straight

5 The black stuff still collects in the stream bed.

Tanya and Karl thought the question we should try to answer was why the water ran slower in the second wiggly stream than in the first straight one. Fred thought it only looked that way and said that the water in both moved about the same speed. Mrs. Gretylock said we could try floating stuff in our streams and measuring how long it would take them if we thought that would work. Tanya said the wiggly stream was longer so it wouldn't be fair. Karl said we should measure our straight stream with a piece of string and then lay it along the wiggly streams so the stuff would float the same distance in each stream. Then we timed with the stopwatch how long it took little bit of paper to move along both lengths of stream

Straight stream	Wiggly Stream
6.3	9.8
12.5	11.2
7.4	paper got stuck
paper got stuck	12.7
6.7	10.3

on this one the paper stuck a little

We think this proves that the wiggly stream runs slower than the straight stream cause it takes longer. We aren't sure yet why the wiggly one runs slower but I think the wiggles may be like the water going down stairs instead of falling straight down.

Fred and Karl think the black stuff may be heavier so they are going to try to find a way to separate it from the other sand. Mrs Greylock said we should try measuring how much higher the beginning of our two streams are than their mouths. Tanya and I will try this next time.

Cindy Cronk

4. Comments on student work:

The initial phase of the investigation, making and recording observations, and setting up the equipment, can be considered EXPLORATION. When the students decide to make their new model look more like a stream with which they are familiar, they are engaged in creating a new model which they can also EXPLORE.

Their non-quantitative notion of the differences in stream velocity represents an interesting phenomenon to be investigated further and one for which a possible explanation is later introduced. Teacher assistance in attacking the problem identified opened a new set of problems, namely, controlling the variable of stream length. Tanya's contention that it "wouldn't be fair" is a way in which students commonly verbalize their intuitive feelings concerning the need to control variables. The data collected by the students lead them to the conclusion that Fred's hypothesis -- streams both streams flow at the same speed -- was not valid.

Cindy's model explanation constitutes a CONCEPT INTRODUCTION. Perhaps Mrs. Gretzlock's suggestion was not as "subtle" as it might have been, but the basis for testing it has been laid. Apparently observations made initially have set Fred and Karl off on a new exploration and they will doubtless pursue it, given time and encouragement.

Discuss the following items with your partner if they did not come up in an earlier conversation.

1. What instances of concrete and formal reasoning can you identify in the student's work?

2. How would you assist students in coming up with reasonable explanations for their observations?

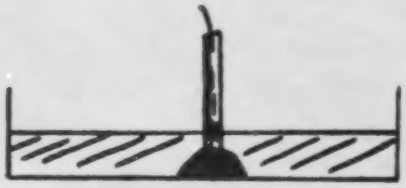
3. Think of some laboratory activities you do with your students. Do they reflect the learning cycle approach? Do they require the students to follow a "recipe"? How might they be changed to help initiate self-regulation?

Review Questions

Please respond to the following questions and then discuss your answers with your partner.

1. Suppose you are asked to develop a laboratory activity to study the concept of atmospheric pressure. Rank the following procedures in terms of how you perceive their effectiveness in initiating self-regulation for your students. Use 1 for most effective and 5 for least effective.

	Rank	
	Self-Regulation	Content
A. Provide students with plastic boxes, cylinders (open at one end), jars and glasses (of various sizes and shapes), matches, water, a ruler, candles, a block of wood, and clay. Have them set up the materials as shown in the figure below. Then light the candle, put a container over the candle and observe what happens. Suggest that they repeat the experiment several times in several ways, record observations, and attempt to explain what happens.	____	____



	Self-Regulation	Content
B. Provide students with plastic boxes, a cylinder (open at one end), matches, water, a candle, and a piece of clay. Have them observe the effect of air pressure by putting the cylinder over the burning candle and observing the candle go out and the water rise into the cylinder. Explain that the water rose because: (1) the heated air expanded and escaped out the bottom of the cylinder, (2) the air cooled and contracted, and (3) this resulted in less air pressure inside the cylinder than outside, therefore, the water rose into the cylinder until the pressures were equal.	____	____

C. Provide students with plastic boxes, cylinders (open at one end), jars and glasses (of various sizes and shapes), matches, water, a ruler, candles, a block of wood, and clay. Have them set up the experiment as described above, and follow this procedure: (1) use one candle and measure water rise, (2) repeat using two, then three, then four candles and measure water rise. Record all data. Note the bubbles escaping from the bottom of the cylinder. Repeat again, this time place the candle in the clay, on the block of wood. Float the block of wood on the water, light the candle, and place the cylinder over the candle and block of wood. Note the water rise after the candle goes out. Attempt to explain what happens. ____ ____

D. Provide students with a flat-sided one gallon can that has a screw cap. (1) Place the can on a hot plate and remove the screw cap. (2) Place two tablespoonfuls of water in the can and boil for several minutes with the screw cap off the top of the can. (3) Remove the can from the heat and stopper the can immediately. (4) Observe and explain what happens when the steam cools. ____ ____

E. Provide students with a plastic cup inverted in a pan of water, and a syring with attached rubber tubing. Challenge them to completely fill the inverted cup with water without turning it over. ____ ____

2. Now reread the list and rank the items according to their effectiveness in transmitting content about atmospheric pressure. Does the ranking agree with your self-regulation ranking? If not, why do you think that there is a difference?

3. Evaluate the five suggested procedures according to their suitability for CONCEPT INTRODUCTION or APPLICATION activities relating to atmospheric pressure.

Our answer to #1:

We would rank the alternatives A, C, E, D, B; alternatives E and D would serve as good APPLICATION activities following the introduction of air pressure as described in the alternative B.

MODULE 6
THE LABORATORY AND SELF-REGULATION

Introduction

Work by Piaget, Bruner, and others studying the development of reasoning in adolescents and adults clearly indicates the need for the learner to (1) actively influence a happening and (2) discuss what he has done, what it means, and how it fits or does not fit with previous ways of thinking. This need gives chemistry laboratory experiences a key role in the development of reasoning. It also suggests that laboratory work has to be planned carefully if it is to promote the use of formal reasoning patterns. The laboratory should be presented in such a way that students actively consider alternate procedures, debate results, and reflect upon implications.

Objectives

To assist you in identifying and designing laboratory experiences that encourage self-regulation and promote the use of formal reasoning patterns.

Procedure

Join three or four fellow participants and begin by doing the exploration activity. Then continue to work with a partner or the entire group, if you wish, as you read the essay on chemistry laboratories. An example laboratory exercise is also provided for you to read and discuss. We hope that by working as a group you will be encouraged to compare notes and exchange ideas during this module. At its conclusion, please proceed to Module 7.

Instructional Materials

1. Exploration

To help you and your partner approach this module in an inventive frame of mind, we ask you to begin with the laboratory investigation introduced on this page. In the module area you will find the following equipment:

test tubes
tubing
vinegar
ruler
stoppers
steel wool
water with food coloring

Rinse some steel wool in vinegar, squeeze it, stuff it into a test tube, and close the test tube with a one-hole stopper fitted with a piece of tubing. Dip the end of the tube into colored water and observe the changes.

Now think of the chemical changes that may be occurring and of the conditions that might affect the process. Make measurements to determine quantitative relationships that seem to interest you. You may use objects in your possession, such as a watch, in addition to the ones provided.

Please record your observations and data here. State any conclusions you reach.

After about ten to twenty minutes, join with a group of other workshop participants to discuss some ways in which the above "exploration" might be followed up in a student laboratory exercise.

Please turn to the next page for the first essay.

2. Essay: The Chemistry Laboratory and Self-Regulation

Suppose you are asked to develop a laboratory exercise on kinetics for beginning chemistry students. Rank the following procedures in terms of how you perceive their effectiveness in encouraging self-regulation for the students; use 1 for the most effective and 4 for the least effective.

Rank

A. Provide the students with the materials and explicit instructions for an iodine clock reaction involving potassium iodate and potassium bisulfite. Require that they verify the relationship between reaction rate and the concentration of KIO_3. ____

B. Provide the students with the materials for an iodine clock reaction. Supply a list of possible variables of the system, i.e., concentration of KIO_3, concentration of $KHSO_3$, concentration of starch solution, and temperature. Supply a list of possible relationships between variables, e.g., the rate is directly proportional to the concentration of any one of the reactants, the rate is directly proportional to the temperature. Ask the students to identify the most accurate relationships between some of the variables. ____

C. Provide the students with a variety of chemical systems which exhibit rate determining processes, e.g., clock reactions, gas evolution reagents, combustion reactions, etc. Ask the students to investigate and identify common variables of these systems. ____

D. Provide the students with materials for the $KHSO_3$ - KIO_3 iodine clock reaction. Indicate that there is a relationship between the rate of the reaction and the concentration of KIO_3. Challenge them to discover the relationship and then to use their data to predict the concentration of KIO_3 required for a 30 minute delay in the appearance of the color. ____

According to our learning cycle model to induce self-regulation, an introductory period of exploration or openness in a laboratory exercise is recommended. Hence, procedures B and C are superior to A and D. Furthermore, C is more open and exploratory than B. Procedure C may encourage the student to examine a number of aspects of a clock reaction that you may not think are important or interesting, but that appear important to him. It enables the students to begin where they are in their understanding of chemical reactions and enlarge their concrete experiences with such systems without having the instructor impose his own reasoning on their activities. Hence, we believe that C is the preferred procedure to use.

Procedure B also provides a good deal of openness while directing the students toward variables determined by the instructor. A variant of this procedure would be a good discovery activity. It tends to focus the activities of the students and make their efforts more efficient if content goals are important. Predictions and expectations in advance of the experiments can be exploited to produce some contradictions in the thinking of the students and start them on self-regulation. Extreme cases not tested directly or concretely can also encourage self-regulation. Hence, we favor procedure D over procedure A. In fact, procedure A has little to recommend it as far as we are concerned.

The social interactions that occur in the laboratory setting are important for starting self-regulation. Testing one's ideas against the ideas of one's peers is a profitable way to spend some time during the laboratory period. Instructor-student dialogues can be very valuable when the instructor asks the student to justify his results. Helping students to become aware of their own thinking is a major function of the instructor if he wishes to encourage his students along the path of self-regulation. Such common thinking tools of chemists as checking the dimensions or units of an answer, making an order of magnitude estimate, and seeing if the answer makes sense at the extreme values of the variables are all aspects of the self-regulation process that can be learned as part of laboratory activities.

At this point it might be helpful to describe how one goes about designing or adapting existing laboratory experiences to fit the EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION cycle. The starting point is the teacher's selection of an interesting phenomenon--an object, event, or situation that (1) students can observe, (2) is amenable to manipulation or description, and (3) leads to the isolation of specific variables. In the exploratory phase of this module, the behavior of a kind of spring oscillator was chosen as the phenomenon. Chemical equilibria or freezing temperatures of water and aqueous solutions are other phenomena that might be investigated.

The steps for successful EXPLORATION, CONCEPT INTRODUCTION, CONCEPT APPLICATION experiences are these:

1. The teacher isolates an interesting object, event, or situation that can be observed in the laboratory.

2. Students are given an initial period in which they freely explore the object, event, or situation, become familiar with it, raise questions about it, attempt to isolate interesting relationships and variables, and search for patterns or generalizations. This is the EXPLORATION phase.

3. These relationships are highlighted by the teacher or by the students and often given names (e.g., "reaction time" to refer to the time for the iodine-starch color to appear, "solubility product" or "ionization constant" in connection with solution equilibria, "dissociation" for the freezing point depression). This the CONCEPT INTRODUCTION phase.

4. Students then conduct further investigation of specific variables that have been isolated and seek to establish definite relationships among them. The teacher introduces new materials that permit investigation of the phenomenon in other contets. For example, after the concept of the "reaction time" has been introduced, investigations of a different iodine clock reaction, a gas evolution reaction, or a combustion reaction would allow for concept reinforcement. This is the CONCEPT APPLICATION phase, which permits students to complete the self-regulation process.

What is the positive benefit of beginning a chemistry lab with the exploratory investigation of some natural phenomenon? In most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in textbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions -- questions that must be answered through "real" inquiries.

Laboratory on Reaction Time

In this exercise, we present a laboratory activity arranged according to the learning cycle into exploration, invention, and discovery. The students were given four pages, one with the title and instruction for EXPLORATION (see below), a second page organized as data sheet,a "CONCEPT INTRODUCTION" and two "CONCEPT APPLICATION" pages. Since the last four pages required student recording of data or answering of questions, we are presenting them in reduced format with the data, answers, and work of one pair of students. Please examine these pages and look for evidence of concrete and formal reasoning patterns, self-regulation, and failures to respond to inconsistencies. Then look at our comments on page 6-9.

The demonstration mentioned at the beginning of the exploration is as follows: (1) the teacher squirts approximately ten drops of the sodium bisulfite solutions into a test tube, then adds about three drops of starch solutions to the bisulfite; (2) with the students watching, the teacher squirts ten drops potassium iodate into the test tube and shakes it, while holding it in a well-illuminated place in front of a white sheet of paper for good visibility. Observation continues until a blue color suddenly appears.

HOW LONG DOES A REACTION TAKE?

Purpose: To investigate the time required by a chemical reaction.

Equipment and materials:

Dropping bottles containing

0.020 M potassium iodate (KIO_3) ✓
0.020 M sodium bisulfite ($NaHSO_3$) ✓ ← $Na_2S_2O_5$ (metabisulfite)
saturated starch solution (0.3%)
distilled water ✓

graduated cylinders (25 ml)
test tubes and rack
thermometer
beakers
alcohol lamp
cracked ice
clock with sweep second hand or laboratory timer
general laboratory equipment

EXPLORATION

To find out what might happen when the materials for the investigation are combined, watch your teacher perform a brief demonstration. You will observe a blue color appear. This blue color is produced by the interaction of iodine and starch to form a complex substance.

After the demonstration, it is your assignment to find out as much as you can about the conditions under which the blue color appears and how long it takes to appear. Watch your classmates' experiments as well as your own to find out more during the lab session.

List the variables that might affect how long it takes before the blue color appears. (If you get more ideas from talking to your classmates or while you experiment, add these to your list.) Make a check mark beside a variable whose effect you have investigated.

Variables of the system: temp, atmospheric pres., concentrations,

Do experiments in which you measure the variables quantitatively and also measure the time before the blue color appears under different conditions. Try to draw some conclusions from your data and discuss them with your classmates.

Please record all your trials, even the ones that "fail" in your opinion. Use the data table on page 2. You will be graded on the completeness of your records as well as the reasonableness of your conclusions.

After you are satisfied that you have examined some aspects of your system, ask your teacher for the Invention Page.

Ⓐ

$10\ KIO_3 + 10\ na_2S_2O_5 + 4$ starch 20 sec

Values of Variables (label the columns)	Time for bl color to app
$5\ H_2O + 5\ HIO_3 + 2\ na_2SO_5$ + starch x	3' 15"
$2\ KIO_3 + 2\ na_2S_2O_5 + 2$ starch	1 min
$2\ KIO_3 + 2\ na_2S_2O_5 + 2$ starch / heat 56°C	10 sec.
$2\ KIO_3 + 2\ na_2S_2O_5 + 2$ starch / cooled 3°c	1 m. 35 s
$2\ KIO_3$ + 2 starch + $2\ H_2O$ / room temp nuthin' happened	

Ⓑ

temp	H_2O	Feb 25	starch	$Na_2S_2O_5$	KIO_3	
25°C shook	—		3 drops.	10 drops	10 drops	20 se
25°C shook	1 ml.		3 drops	10 drops	10 drops	1 min.
14°C shook			3 drops	10 drops	10 drops	25 sec.
25°C shook			1	5	5	20 sec
25°C not shook			1	5	5	17 sec.
25°C shook			5	5	5	30 sec
25°C no shook			5	—	5	2 sec
25°C shook		Feb 26	5	—	5	no reactio
25°C shook			5	5		no reactic
25°C shook			1	5 dr.	5 dr	20 sec
			added 5 more drops bisulfite didn't stay blue added 5 more drops KIO_3 blue color came back			
62°C no shook			3	10	10	15 sec.

Janet McCormic

CONCEPT INTRODUCTION

You may have wondered why the blue-black color appeared so suddenly in your test tube after you waited for a while. To understand the reason, you have to realize the following:

1. The blue-black color is evidence that the element iodine is present in the solution and has reacted with starch.
2. Potassium iodate and sodium bisulfite react in a complicated way that leads to the production of iodine after all the bisulfite has been used up.

If you put these facts together, you realize that the blue-black color indicating iodine and starch (fact 1) only appears after the bisulfite has been consumed in the reactions (fact 2). Apparently, it takes some time for the reactions to use up the bisulfite. That is the time you had to wait for the color. After the bisulfite was used up, iodine was formed (fact 2) and gave the blue-black color (fact 1).

Even though many chemical reactions occur so quickly that you don't have to wait for color to change or precipitates to form, every reaction requires a certain time. This is called the elapsed time of the reaction. In this experiment you observed the elapsed time of the reactions consuming potassium bisulfite.

To answer the following two questions, compare your results with your classmates.

1. Which variables of the system had an effect on the elapsed time of the reaction? temp, concentration of KIO_3, $Na_2S_2O_5$, starch, lack of elements needed for reaction,
2. Which variables of the system seemed to have little effect on the elapsed time of the reaction? test tubes, lighting, pressure

After you write down your answers, ask your teacher for Applications I.

APPLICATION I

What relationships can you find between the variables of this system and the elapsed time of the potassium iodate - potassium bisulfite reaction? Look over your data on the Exploration page to see what you have found out. You might draw line graphs that show how the elapsed time depends on each of the variables.

What conclusions can you reach, based on your data? Write them here.

Ⓐ 1.) higher the temp. the shorter the elapsed time.

2.) lower the temp. the longer the elapsed time.

3.) lower concentrations of KIO_3, $Na_2S_2O_5$; starch, the longer the reaction times.

4.) higher concentrations of " , " , " , the shorter the reaction times

5.) More starch slows down the reaction time.

Ⓑ 1) temperature effects the reaction

2) concentration also effects the reaction

3) if the $Na_2S_2O_5$ is doubled, the length of time for the blue to appear is increased.

4) the amount of bisulfate to the amount of KIO_3 also makes a difference.

Compare your conclusions with those of other students in your class. How do your conclusions agree with theirs? How do they disagree? Describe the similarities and differences here.

Think again about your conclusions. Perhaps you should change your mind about some of them. Perhaps your classmates will change their minds. What do you think?

Continue to Application II.

APPLICATION II

Do you think you can put together a chemical system so that the elapsed time of the potassium iodate - potassium bisulfite reaction is close to 1000 seconds? Look over your data from the exploration to help you select the amounts of reactants and the conditions you would need.

Note: If you think you don't have enough information at this time, either:

(a) check with your teacher or another student and explain your problem

OR

(b) describe what experiments you have to do so you will know how to put the system with 1000 second elapsed time together.

Here are some suggestions to help you with (b):

1. Look back at the Invention Page to find the variables that affect the elapsed time.
2. Describe the effect of each variable by drawing a line graph that shows the variable and the reaction time. Do more experiments if you need more data. Remember--for this graph, all other variables have to stay the same.
3. Now look at your graphs and see whether you can figure out how to put together a system with 1000-seconds elapsed time.

Describe your system here:

Put together the system you described. Measure the elapsed time. Was it close to 1000 seconds? Describe what you found out. Add any explanations you think may be helpful.

Comments on student work:

On pages 1 and 3, most students give very similar answers; we have, therefore, reproduced only those of one team. Since student approaches on pages 2 and 4 varied more widely, we have included work of two teams, designated A and B.

Team A carried out six trials during the exploration phase and no additional ones during discovery. The first trial reproduced the conditions of the teacher demonstration. The third, fourth, and fifth are a systematic effort to investigate the effect of temperature while keeping the reagent mixture the same--evidence of a formal reasoning pattern.

Team A's conclusion are all phrased in the form of seriations and correspondences, and thus indicate concrete reasoning patterns. This team did not respond to the suggestion of drawing a line graph to permit the display of functional relationships, even though the data to do so with respect to temperature were available. Not also how the conclusions are stated in complementary pairs that really say the same thing.

Team B carried out seven trials during exploration and an additional four during discovery. One pair of trials--the fourth and fifth of the first day--concerns the effect of shaking. This variable was not listed by the team on page 1 and apparently occurred to the students while they were exploring. Unfortunately, the conclusions do not refer to this comparison; in such a case, the teacher might ask the students orally to describe what they found out.

This team's trials reveal only pairwise comparisons that indicate the formal reasoning patterns involved in systematic experimentation but not those contributing to the understanding and formulation of functional relationships. The first two conclusions are qualitative, as might be expected. Conclusions 3 and 4 refer to ratios but do not follow these up quantitatively.

Teams A and B did not have time to respond to Application II on page 5. Some of the other teams identified low concentration and low temperature as conditions that would lengthen the reaction time. A few students applied a proportion involving their observed time and amounts, and the 1000 seconds leading to predicted amounts. Since no team in the class investigated functional relationships, they had only a very rough basis for making the prediction.

Discuss the following items with your partner if they did not come up previously:

1. On what data are Team A's conclusions 3, 4, and 5 based? Was the evidence conclusive?

2. On what data are Team B's four conclusions based? In what respects was the evidence insufficient?

3. How would you guide Team A and/or Team B into self-regulation with respect to functional relationships?

Review Questions

Please discuss your ideas with your partner before or after writing down your answer.

1. Suppose you are asked to design a laboratory exercise on the topic of Le Chatelier's principle. Your objective is to encourage self-regulation while teaching your students chemistry. What would be the initial laboratory activity, given the materials in a well-supplied high school chemistry lab?

2. Examine the students' report in this module to find evidence of their using concrete reasoning patterns at some points, formal reasoning patterns at others, in addition to the examples mentioned in our earlier comments.

3. Think about some laboratory activities in your chemistry course. Do they reflect the learning cycle approach? How much do they tell about your students' reasoning patterns? How might they help to initiate self-regulation with respect to testing hypotheses, using functional relationships, and/or considering all possible combinations of experimental conditions.

MODULE 7
CONCRETE AND FORMAL CONCEPTS

Introduction

Many physics teachers think about their courses in terms of topics covered, concepts explained, and principles applied. Our effort in this workshop has been to call your attention to another important dimension of physics teaching, your students' patterns of reasoning. By this time, you have probably concluded that many parts of a physics course are addressed to students who use formal reasoning patterns, and we would agree with that. Yet, there are students whose use of formal reasoning patterns is very limited. We, therefore, suggest that you think about physics concepts according to the reasoning patterns necessary to understand the meaning you wish to communicate. Concepts may then be called "concrete" or "formal," in analogy to the stages of reasoning. When you plan your teaching, you can begin with "concrete" concepts and gradually progress to "formal" concepts. This module presents examples and explanations of "concrete" and "formal" concepts.

Objectives

To assist you in classifying physics concepts on the basis of the patterns of reasoning needed to understand them.

To assist you in sequencing instruction so as to encourage self-regulation.

Procedure

We have arranged this module in the form of a learning cycle built around the distinction between concrete and formal concepts. Please find a partner with whom you can join in the activities. Then undertake the activities described in the attached instructional materials. Proceed to Module 8 after you conclude the Review Questions.

Instructional Materials

1. Exploration

Below are five concepts introduced in some introductory physics courses. Decide whether a student could develop an initial understanding of these concepts through (1) direct experience and the use of concrete reasoning patterns (classification, conservation, one-to-one correspondence), or (2) inferences from experience and formal reasoning patterns (reasoning with theories, models, other concepts).

Begin by briefly describing to your partner some ways in which you would help your students understand each of the concepts listed. Then classify the concepts according to (1) or (2) above.

Interaction:

Electrical Conductor:

Ideal Gas:

Light Wave:

Potential Energy:

Please complete this activity and come to an agreement with your partner before continuing with the invention on the next page.

2. Concept Introduction: Concrete and Formal Concepts

In our opinion, "interaction" and "electrical conductor" can readily be understood in terms of familiar actions, observations, and examples. In other words, these concepts can be derived from direct experience by using concrete reasoning patterns. Such concepts are called concrete concepts.

The concepts of "ideal gas," "light wave," and "potential energy" must be understood in terms of other concepts (pressure, volume, electric field force), functional relationships (ideal gas law, wave function), inferences, and/or idealization. These understandings are not the result of direct experiences and require application of formal reasoning patterns. Such concepts are called formal concepts.

Some concepts, of course, have more than one meaning and may, therefore, be "concrete" or "formal," depending on their treatment. Thus, temperature as read on a thermometer is a "concrete" concept; temperature as a measure of the average molecular kinetic energy is a "formal" concept. Before being classified, therefore, a concept must be defined clearly.

It may be good to mention at this time that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and concrete examples.

Interaction is abstract in that it is very general, applicable to all objects that influence one another, regardless of whether they exchange energy or momentum, modify the chemical composition, or (if living) infect with a disease. Since numerous direct experiences are readily available to illustrate the meaning of interaction, interaction is a "concrete" concept and has been taught successfully to second and third graders.

The light wave concept is also abstract, though more restricted in applicability than interaction. Yet the meaning of light wave depends essentially on Maxwell's electromagnetic theory, which can be understood only through the use of propositional reasoning, functional relationships, abstract variables, idealized models, and other formal reasoning patterns. Hence, light wave is a "formal" concept.

The analysis of concepts is, of course, not exhausted by the points we have raised above. We realize, also, that some educators use the term concept with a somewhat different significance than we have given it. We believe, however, that our distinction between concrete and formal concepts can be applied beneficially without detailed examination of these other issues.

3. Concept Application

To allow you to apply your present understanding of the distinction between concrete and formal concepts, we have constructed a list of items we should like you to classify. Discuss each item with your partner to help you clarify your ideas, but record your own views if you two disagree. To help you justify your classifications, we have included here a slightly edited version of the concrete and formal reasoning patterns originally given in Module 2.

The concrete reasoning patterns most frequently required for the understanding of physics concepts are:

C1. understands concepts defined in terms of familiar actions and examples that can be observed directly;

C2. applies conservation reasoning to objects;

C3. establishes one-to-one correspondences and arranges data in increasing or decreasing sequence ;

C4. makes simple classifications and successfully relates systems to subsystems, classes to subclasses;

The formal reasoning patterns most frequently required for the understanding of physics concepts are:

F1. understands concepts defined in terms of other concepts or through abstract relationships such as ratios or mathematical limits;

F2. imagines all possible combinations of conditions even though not all may be realized in nature ;

F3. separates the effects of several variables by varying only one at a time;

F4. uses theories or idealized models ;

F5. recognizes and applies functional relationships, such as direct and inverse proportion;

F6. understands the nature of probability and recognizes its implications for experimental design and data analysis.

The differences between these reasoning patterns might be summarized as follows: the concrete patterns apply simple operations to real objects and experiences, but not to relationships, hypothesized objects, or postulated properties. A concept can usually be considered "concrete," therefore, if one can grasp its meaning through direct experience. If a concept derives its meaning principally from its position within a theoretical system, it has to be classified as "formal."

Here are the concepts for your exercise. We have included answers for the first two items to illustrate how you might refer to the above lists of reasoning patterns when you give your reasons.

Here are the concepts for your exercise. We have included our answers for the first two items to illustrate how you might refer to the above lists of reasoning patterns when you give your reasons.

	Concept	C or F	Reasons
1.	Succession	C	Defined descriptively through examples of changes in vegetation as a pond is filled with silt. Requires simple classification (C4) and serial ordering (C3).
		F	Defined by means of changes in environmental conditions that lead to successful competition of new species of plants with those established earlier under differing conditions (F1, F2). Individual species are related to the entire ecosystem.
2.	Hardy-Weinberg Law	F	Requires reasoning about hypothesized systems and entities (genes) (F4), understanding of probability (F6), ability to generate all possible combinations of genotypes (F2), and ability to apply quantitative proportional relationships (F5). Note: there is an algorithm for solving genetics problems involving the Hardy-Weinberg law that can lead to correct answers by use of concrete reasoning patterns in very simple situations.
3.	Population		
4.	Photosynthesis		
5.	Digestion		
6.	Meiosis		

7. Enzymatic Action

8. Community of Organisms

Recall that the student who uses primarily concrete reasoning patterns does not reason beyond concrete objects, events, or experiences, has little power of reflection, and does not construct theoretical systems. Hearing a lecture or reading about genes, DNA replication, natural selection, or other formal concepts will not provide such a student with the necessary background of experience to understand these concepts. Instead, instruction should begin with exploratory experiences and "concrete" concepts.

The fact that some biology concepts can be interpreted either as concrete or formal helps in finding a teaching procedure that may lead to self-regulation. Learning that begins with a concrete version of a concept is likely to make a more secure connection with the student's previous understandings and preconceptions.

The learning cycle then affords a way for teaching to achieve self-regulation with respect to the formal version of the concept. Most biology students are likely to have an understanding of temperature, environment, species, and predator as "concrete" concepts. Through exploration activities they can apply their understanding and also discover its limitations -- for instance, the difficulty of distinguishing between similar species on the basis of easily observed characteristics.

Here you will find some differences among your students, for some begin self-regulation much more quickly than others. For this reason you should make allowances in the amount of time available for experimentation by different students.

Please look back at the above concept list now, and do the following together with your partner: for each item that you classified on two or more levels, think of an activity that would bring out the shortcomings of the concrete version and thereby initiate self-regulation.

Review Questions

Please work on these items together with your partner.

1. Name two biology concepts that can only be understood by use of formal reasoning patterns (i.e., they have no "concrete" version).

2. Name two biology concepts for which you can identify two or more levels of meaning. Briefly define each level.

3. Select one of the concepts you have named in #1 or #2, or a concept mentioned earlier in this module, and briefly work out a learning cycle of exploration, concept introduction, and application that might be built around it.

4. Compare the learning activities that might be used for a "formal" concept with those that might be appropriate for a "concrete" concept (or a concrete version of the same concept).

MODULE 7
CONCRETE AND FORMAL CONCEPTS

Introduction

Many biology teachers think about their courses in terms of topics covered, concepts explained, and principles applied. Our effort in this workshop has been to call your attention to another important dimension of biology teaching, your students' patterns of reasoning. By this time, you have probably concluded that many parts of a biology course are addressed to students who use formal reasoning patterns, and we would agree with that. Yet, there are students whose use of formal reasoning patterns is very limited. We, therefore, suggest that you think about biology concepts according to the reasoning patterns necessary to understand the meaning you wish to communicate. Concepts may then be called "concrete" or "formal," in analogy to the stages of reasoning. When you plan your teaching, you can begin with "concrete" concepts and gradually progress to "formal" concepts. This module presents examples and explanations of "concrete" and "formal" concepts.

Objectives

To assist you in classifying biology concepts on the basis of the patterns of reasoning needed to understand them.

To assist you in sequencing instruction so as to encourage self-regulation.

Procedure

We have arranged this module in the form of a learning cycle built around the distinction between concrete and formal concepts. Please find a partner with whom you can join in the activities. Then undertake the activities described in the attached instructional materials. Proceed to Module 8 after you conclude the Review Questions.

Instructional Materials

1. Exploration

Below are five concepts introduced in many biology courses. Decide whether a student could develop an initial understanding of these concepts through (1) direct experience and the use of concrete reasoning patterns (classification, conservation, one-to-one correspondence) or (2) inferences from experience and formal reasoning patterns (reasoning with theories, models, other concepts).

Begin by briefly describing to your partner some ways in which you would help your students understand each of the concepts listed. Then classify the concepts according to (1) or (2) above.

Gene:

Species:

DNA Replication:

Environment:

Natural Selection:

Please complete this activity and come to an understanding with your partner before continuing with the invention on the next page.

2. Concept Introduction: Concrete and Formal Concepts

In our opinion, "species" and "environment" can readily be understood in terms of familiar actions, observations, and examples. In other words, these concepts can be derived from direct experience by using concrete reasoning patterns. Such concepts are called concrete concepts.

The concepts of "gene," "DNA replication," and "natural selection" must be understood in terms of other concepts (trait, heredity, cell, molecular structure, competition, environmental factors), functional relationships, inferences, and/or idealized models. These understandings are not the result of direct experiences and require application of formal reasoning patterns. Such concepts are called formal concepts.

Some concepts, of course have more than one meaning and may, therefore, be "concrete" or "formal," depending on their treatment. For example, the concept of habitat, if defined as a place where an organism lives, is a "concrete" concept. Indeed this meaning of habitat has been sucessfully taught to first graders. However, if habitat is defined as Hutchinson defines niche, as "an n-dimensional hypervolume every point of which corresponds to an environmental state permitting the species in question to maintain a steady state," the concept is clearly a "formal" one. This concept causes some graduate students difficulty.

It may be good to mention at this time that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and concrete examples.

Environment is very abstract and general since it applies to individual cells, to entire multicellular organisms, to populations of organisms, and so on. Nevertheless, once it is abstracted, numerous concrete experiences are readily available to demonstrate its meaning.

The concept of gene is also an abstraction; however, it is a different kind of abstraction. Mendel hypothesized the existence of "factors" to explain ratios of characteristics obtained through hybridized crosses of pea plants. The factors, or genes, themselves did not give rise to concrete experience. The gene concept has to be understood in terms of other concepts (heredity, trait), the possible combinations of genes that produce observable effects, and a theory relating genotype to phenotype. Hence the concept of gene is "formal."

The analysis of concepts is, of course, not exhausted by the points we have raised above. We realize, also, that some educators use the term concept with a somewhat different significance than we have given it. We believe, however, that our distinction between concrete and formal concepts can be applied beneficially without detailed examination of these other issues.

3. Concept Application

To allow you to apply your present understanding of the distinction between "concrete" and "formal" concepts, we have constructed a list of items we should like you to classify. Discuss each item with your partner to help you clarify your ideas, but record your own views if you disagree. To help you justify your classifications, we have included here a slightly edited version of the concrete and formal reasoning patterns originally given in Module 2.

The concrete reasoning patterns most frequently required for the understanding of biology concepts are:

C1. understands concepts defined in terms of familiar actions and examples that can be observed directly;

C2. applies conservation reasoning to objects;

C3. establishes one-to-one correspondences and arranges data in increasing or decreasing sequence;

C4. makes simple classifications and successfully relates systems to subsystems, classes to subclasses.

The formal reasoning patterns most frequently required for the understanding of biology concepts are:

F1. understands concepts defined in terms of other concepts or through abstract relationships such as ratios or mathematical limits;

F2. imagines all possible combinations of conditions even though not all may be realized in nature;

F3. separates the effects of several variables by varying only one at a time;

F4. uses theories or idealized models;

F5. recognizes and applies functional relationships, such as direct and inverse proportion;

F6. understands the nature of probability and recognizes its implications for experimental design and data analysis.

The differences between these reasoning patterns might be summarized as follows: the concrete patterns apply simple operations to real objects and experiences, but not to relationships, hypothesized objects, or postulated properties. A concept can usually be considered "concrete," therefore, if one can grasp its meaning through direct experience. If a concept derives its meaning principally from its position within a theoretical system, it has to be classified as "formal."

Concept	C or F	Reasons
1. Pressure	C	Defined operationally through a barometer reading, with pressure differences defined by a manometer (C1). Pressures can be compared (C3).
	F	The usual definition, force per unit area, depends on the force concept (F1) and on proportions (F5). Pressure can be use to calculate gas volumes or forces exerted on container surfaces.
	F+	Pressure is the time-average effect of molecular bombardment of the containing surface (F1, F4, F5). This concept derives its meaning from the kinetic-molecular theory, a theoretical system in Modern physics.
2. Shadow	C	Can be observed easily and is familiar (C1). Correspondence of obstacle shape and shadow shape can be established (C3), as can qualitative size relationships.
	F	Ratio and proportions are used to describe size relations of obstacle and shadow in terms of light source, obstacle, and shadow positions (F3, F5).
	F+	The concept of shadow is qualified by the diffraction of light according to the wave theory (F4). This concept's meaning is affected by the theoretical system of the electromagnetic theory of light. (Note: introduction of the quantum theory would escalate the conceptual level another step).
3. Temperature		
4. Vertical		
5. Acceleration		

6. Wave
   Interference

7. Potential
   Energy

Recall that the student who uses primarily concrete reasoning patterns does not reason beyond concrete objects, events, or experiences, has little power of reflection, and does not construct theoretical systems. Hearing a lecture or reading about ideal gases, light waves, potential energy, or other formal concepts will not provide such a student with the necessary background of experience to understand these concepts. Instead, instruction should begin with exploratory experiences and "concrete" concepts.

The fact that some physics concepts can be interpreted either as "concrete" or "formal" helps in finding a teaching procedure that may lead to self-regulation. Learning that begins with a concrete version of a concept is likely to make a more secure connection with the student's previous understandings and preconceptions.

The learning cycle then affords a way for teaching to achieve self-regulation with respect to the formal version of the concept. Most physics students are likely to have an understanding of temperature, pressure, force, and speed as "concrete" concepts. Through exploration activities they can apply their understanding and also discover its limitations -- for instance, the difficulty of making quantitative predictions from pressure defined completely in terms of a barometer reading.

Here you will find some differences among your students, for some begin self-regulation much more quickly than others. For this reason you should make allowances in the amount of time available for experimentation by different students.

Please look back at the above concept list now, and do the following together with your partner: for each item that you classified on two or more levels, think of an activity that would bring out the shortcomings of the concrete version and thereby initiate self-regulation.

Review Questions

Please work on these items together with your partner.

1. Name two physics concepts that can only be understood by use of formal reasoning patterns (i.e., they have no "concrete" version).

2. Name two physics concepts for which you can identify two or more levels of meaning. Briefly define each level.

3. Select one of the concepts you have named in #1 or #2, or a concept mentioned earlier in this module, and briefly work out a learning cycle of exploration, concept introduction, and application that might be built around it.

4. Compare the learning activities that might be used for a "formal" concept with those that might be appropriate for a "concrete" concept (or the concrete version of the same concept).

MODULE 7
CONCRETE AND FORMAL CONCEPTS

Introduction

Many general science teachers think about their courses in terms of topics covered, concepts explained, and principles applied. Our effort in this workshop has been to call your attention to another important dimension of general science teaching, your students' patterns of reasoning. By this time, you have probably concluded that many parts of a general science course are addressed to students who use formal reasoning patterns, and we would agree with that. Yet, there are students whose use of formal reasoning patterns is very limited. We, therefore, suggest that you think about general science concepts according to the reasoning patterns necessary to understand the meaning you wish to communicate. Concepts may then be called "concrete" or "formal," in analogy to the stages of reasoning. When you plan your teaching, you can begin with "concrete" concepts and gradually progress to "formal" concepts. This module presents examples and explanations of "concrete" and "formal" concepts.

Objectives

To assist you in classifying general science concepts on the basis of the patterns of reasoning needed to understand them.

To assist you in sequencing instruction so as to encourage self-regulation.

Procedure

We have arranged this module in the form of a learning cycle built around the distinction between concrete and formal concepts. Please find a partner with whom you can join in the activities. Then undertake the activities described in the attached instructional materials. Proceed to Module 8 after you conclude the Review Questions.

Instructional Materials

1. Exploration

Below are five concepts introduced in many general science courses. Decide whether a student could develop an initial understanding of these concepts through (1) direct experience and the use of concrete reasoning patterns (classification, conservation, one-to-one correspondence) or (2) inferences from experience and formal reasoning patterns (reasoning with other theories, models, concepts).

Begin by briefly describing to your partner some ways in which you would help your students understand each of the concepts listed. Then classify the concepts according to (1) or (2) above.

Density:

Particle Model:

Genotype:

Solution (liquid):

Cell:

Please complete this activity and come to an understanding with your partner before continuing with the invention on the next page.

2. Concept Introduction: Concrete and Formal Concepts

In our opinion, "solution" and "cell" can readily be understood in terms of familiar actions, observations (through a microscope), and examples. In other words, these concepts can be derived from direct experience by using concrete reasoning patterns. Such concepts are called concrete concepts.

The concepts of "density," "particle model," and "genotype" must be understood in terms of other concepts (mass, volume, gene, inherited trait), functional relationships (ratio), inferences, postulates, and/or idealized models. These understandings are not the result of direct experiences and require application of formal reasoning patterns. Such concepts are called formal concepts.

Some concepts, of course, have more than one meaning and may, therefore, be "concrete" or "formal," depending on their treatment. Thus, temperature as read on a thermometer is a "concrete" concept; temperature as a measure of the average molecular kinetic energy is a "formal" concept. Before being classified, therefore, a concept must be defined clearly.

It may be good to mention at this time that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and concrete examples.

Interaction is abstract in that it is very general, applicable to all objects that influence one another, regardless of whether they exchange energy or momentum, modify the chemical composition, or (if living) infect with a disease. Since numerous direct experiences are readily available to illustrate the meaning of interaction, interaction is a "concrete" concept and has been taught successfully to second and third graders.

The genotype concept also is abstract, though more restricted in appliccability than interaction. Yet the meaning of genotype depends essentially on the Mendelian theory of inheritance, which can be understood only through hypothetico-deductive reasoning applied to certain postulates (genes which control certain inherited traits are chemical materials that are passed from parent to offspring, genes occur in pairs, genes make up chromosomes, etc.). Since understanding the genotype concept requires this and other formal reasoning patterns, genotype is a "formal" concept.

The analysis of concepts is, of course, not exhausted by the points we have raised above. We realize, also, that some educators use the term concept with a somewhat different siginificance than we have given it. We believe, however, that our distinction between concrete and formal concepts can be applied beneficially without detailed examination of these other issues.

3. Concept Application

To allow you to apply your present understanding of the distinction between "concrete" and "formal" concepts, we have constructed a list of items we should like you to classify. Discuss each item with your partner to help you clarify your ideas, but record your own views if you disagree. To help you justify your classification, we have included here a slightly edited version of the concrete and formal reasoning patterns originally given in Module 2.

The concrete reasoning patterns most frequently required for the understanding of general science are:

C1. understands concepts defined in terms of familiar actions and examples that can be observed directly;

C2. applies conservation reasoning to objects;

C3. establishes one-to-one correspondences and arranges data in increasing or decreasing sequence;

C4. makes simple classifications and successfully relates systems to subsystems, classes to subclasses.

The formal reasoning patterns most frequently required for the understanding of general science concepts are:

F1. understands concepts defined in terms of other concepts or through abstract relationships such as ratios or mathematical limits;

F2. imagines all possible combinations of conditions even though not all may be realized in nature;

F3. separates the effects of several variables by varying only one at a time;

F4. uses theories or idealized models;

F5. recognizes and applies functional relationships, such as direct and inverse proportion;

F6. understands the nature of probability and recognizes it implications for experimental design and data analysis.

The differences between these reasoning patterns might be summarized as follows: the concrete patterns apply simple operations to real objects and experiences, but not to relationships, hypothesized objects, or postulated properties. A concept can usually be considered "concrete," therefore, if one can grasp its meaning through direct experience. If a concept derives its meaning principally from its position within a theoretical system, it has to be classified as "formal."

Here are the concepts for your exercise. We have included our answers for the first two items to illustrate how you might refer to the above lists of reasoning patterns when you give your reasons.

Concept	C or F	Reasons
1. Pressure	C	Defined operationally through a barometer reading, with pressure differences defined by a manometer (C1). Pressures can be compared (C3).
	F	The usual definition, force per unit area, depends on the force concept (F1) and on proportions (F5). Pressure can be used to calculate gas volumes or forces exerted on container surfaces.
	F+	Pressure is the time-average effect of molecular bombardment of the containing surface (F1, F4, F5). This concept derives its meaning from the kinetic-molecular theory, a theoretical system in modern physics.
2. Closed Electric Circuit	C	Directly observable circuit elements in operation attached to a battery by visible wires (C1, C4).
	F	A closed path along which electric current might flow, even though a bulb or other circuit elements might not be operating because the current is too small (F1, F4). The possibility of more sensitive indicators is considered, as is the possibility of concealed interruption of the current path (F2, F3).
3. Sense Organ		
4. Mass		
5. Human Variation		
6. Mitosis		

7. Hydrolysis

8. Energy

9. Enzyme

Recall that the student who uses primarily concrete reasoning patterns does not reason beyond concrete objects, events, or experiences, has little power of reflection, and does not construct theoretical systems. Hearing a lecture or reading about density, particle models, genotypes, or other formal concepts will not provide such a student with the necessary background of experience to understand these concepts. Instead, instruction should begin with exploratory experiences and "concrete" concepts.

The fact that some general science concepts can be interpreted either as "concrete" or "formal" helps in finding a teaching procedure that may lead to self-regulation. Learning that begins with a concrete version of a concept is likely to make a more secure connection with the student's previous understandings and preconceptions.

The learning cycle then affords a way for teaching to achieve self-regulation with respect to the formal version of the concept. Most general science students are likely to have an understanding of temperature, pressure, digestion, and solution as "concrete" concepts. Through exploration activities they can apply their understanding and also discover its limitations -- for instance, the difficulty of making quantitative predictions from pressure defined completely in terms of a barometer reading.

Here you will find some differences among your students, for some begin self-regulation much more quickly than others. For this reason you should make allowances in the amount of time available for experimentation by different students.

Please look back at the above concept list now, and do the following together with your partner: for each item that you classified on two or more levels, think of an activity that would bring out the shortcomings of the concrete version and thereby initiate self-regulation.

Review Questions

Please work on these items together with your partner.

1. Name two general science concepts that can only be understood by use of formal reasoning patterns (i.e., they have no "concrete" version).

2. Name two general science concepts for which you can identify two or more levels of meaning. Briefly define each level.

3. Select one of the concepts you have named in #1 or #2, or a concept mentioned earlier in this module, and briefly work out a learning cycle of exploration, concept introduction, and application that might be built around it.

4. Compare the learning activities that might be used for a "formal" concept with those that might be appropriate for a "concrete" concept (or the concrete version of the same concept).

MODULE 7
CONCRETE AND FORMAL CONCEPTS

Introduction

Many earth science teachers think about their courses in terms of topics covered, concepts explained, and principles applied. Our effort in this workshop has been to call your attention to another important dimension of earth science teaching, your students' patterns of reasoning. By this time, you have probably concluded that many parts of an earth science course are addressed to students who use formal reasoning patterns, and we would agree with that. Yet, there are students whose use of formal reasoning patterns is very limited. We, therefore, suggest that you think about earth science concepts according to the reasoning patterns necessary to understand the meaning you wish to communicate. Concepts may then be called "concrete" or "formal," in analogy to the stages of reasoning. When you plan your teaching, you can begin with "concrete" concepts and gradually progress to "formal" concepts. This module presents examples and explanations of "concrete" and "formal" concepts.

Objectives

To assist you in classifying earth science concepts on the basis of the patterns of reasoning needed to understand them.

To assist you in sequencing instruction so as to encourage self-regulation.

Procedure

We have arranged this module in the form of a learning cycle built around the distinction between concrete and formal concepts. Please find a partner with whom you can join in the activities. Then undertake the activities described in the attached instructional materials. Proceed to Module 8 after you conclude the Review Questions.

Instructional Materials

1. Exploration

Below are five concepts introduced in many earth science courses. Decide whether a student could develop an initial understanding of these concepts through (1) direct experience and the use of concrete reasoning patterns (classification, conservation, one-to-one correspondence) or (2) inferences from experience and formal reasoning patterns (reasoning with other theories, models, concepts).

Begin by briefly describing to your partner some ways in which you would help your students understand each of the concepts listed. Then classify the concepts according to (1) or (2) above.

Mineral:

Metamorphism:

Sea Floor Spreading:

Water Cycle:

Erosion:

Please complete this activity and come to an agreement with your partner before continuing with the invention on the next page.

2. Concept Introduction: Concrete and Formal Concepts

In our opinion, "mineral" and "erosion" can readily be understood in terms of familiar actions, observations, and examples. In other words, these concepts can be derived from direct experience by using concrete reasoning patterns. Such concepts are called concrete concepts.

The concepts of "water cycle," "metamorphism," and "sea floor spreading" must be understood in terms of other concepts (evaporation, diffusion, pressure, phase change, earth's crust), functional relationships, inferences, and/or idealized models. These understandings are not the result of direct experiences and require application of formal reasoning patterns. Such concepts are called formal concepts.

Some concepts, of course have more than one meaning and may, therefore, be "concrete" or "formal," depending on their treatment. Thus, temperature as read on a thermometer is a "concrete" concept; temperature as a measure of the average molecular kinetic energy is a "formal" concept. Before being classified, therefore, a concept must be defined clearly.

It may be good to mention at this time that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and concrete examples.

The concept of interaction, for instance, is abstract in that it is very general, applicable to all objects that influence one another, regardless of whether they exchange energy or momentum, modify the chemical composition, or (if living) infect with a disease. Since numerous direct experiences are readily available to illustrate the meaning of interaction, interaction is a "concrete" concept and has been taught successfully to second and third graders.

The water cycle concept is also abstract, though more restricted in applicability than interaction. Yet the meaning of the water cycle depends on understanding the concepts of transpiration, evaporation, diffusion, convection, and condensation, evaluating the effects of variables such as temperature, wind velocity, and earth surface conditions, and relating these to the atmosphere as a large physical system. Hence water cycle is a "formal" concept.

The analysis of concepts is, of course, not exhausted by the points we have raised above. We realize, also, that some educators use the term concept with a somewhat different significance than we have given it. We believe, however, that our distinction between concrete and formal concepts can be applied beneficially without detailed examination of these other issues.

3. Concept Application

To allow you to apply your present understanding of the distinction between "concrete" and "formal" concepts, we have constructed a list of items we should like you to classify. Discuss each item with your partner to help you clarify your ideas, but record your own views if you two disagree. To help you justify your classifications, we have included here a slightly edited version of the concrete and formal reasoning patterns originally given in Module 2.

The concrete reasoning patterns most frequently required for the understanding of earth science concepts are:

C1. understands concepts defined in terms of familiar actions and examples that can be observed directly ;

C2. applies conservation reasoning to objects ;

C3. establishes one-to-one correspondences and arranges data in increasing or decreasing sequence ;

C4. makes simple classifications and successfully relates systems to subsystems, classes to subclasses .

The formal reasoning patterns most frequently required for the understanding of earth science concepts are:

F1. understands concepts defined in terms of other concepts or through abstract relationships such as ratios or mathematical limits ;

F2. imagines all possible combinations of conditions even though not all may be realized in nature ;

F3. separates the effects of several variables by varying only one at a time ;

F4. uses theories or idealized models;

F5. recognizes and applies functional relationships, such as direct and inverse proportion ;

F6. understands the nature of probability and recognizes its implications for experimental design and data analysis.

The differences between these reasoning patterns might be summarized as follows: the concrete patterns apply simple operations to real objects and experiences, but not to relationships, hypothesized objects, or postulated properties. A concept can usually be considered "concrete," therefore, if one can grasp its meaning through direct experience. If a concept derives its meaning principally from its position within a theoretical system, it has to be classified as "formal."

Here are the concepts for your exercise. We have included answers for the first two items to illustrate how you might refer to the above lists of reasoning patterns when you give your reasons.

	Concept	C or F	Reasons
1.	Pressure	C	Defined operationally through a barometer reading, with pressure differences defined by a manometer (C1). Pressures can be compared (C3).
		F	The usual definition, force per unit area, depends on the force concept (F1) and on proportions (F5). Pressure can be use to calculate gas volumes or forces exerted on container surfaces.
		F+	Pressure is the time-average effect of molecular bombardment of the containing surface (F1, F4, F5). This concept derives its meaning from the kinetic-molecular theory, a theoretical system in modern physics.
2.	Mineral Hardness	C	Can be directly observed by students. Involves simple classification (C4), one-to-one correspondence, and serial ordering (C3).
3.	Relative Humidity		
4.	Weathering		
5.	Coriolis effect		

6. Eclipse

7. Aquifer

8. Anticline

9. Season

Recall that the student who uses primarily concrete reasoning patterns does not reason beyond concrete objects, events, or experiences, has little power of reflection, and does not construct theoretical systems. Hearing a lecture or reading about the water cycle, metamorphism, sea floor spreading, or other "formal" concepts will not provide such a student with the necessary background of experience to understand these concepts. Instead, instruction should begin with exploratory experiences and "concrete" concepts.

The fact that some earth science concepts can be interpreted either as "concrete" or "formal" helps in finding a teaching procedure that may lead to self-regulation. Learning that begins with a concrete version of a concept is likely to make a more secure connection with the student's previous understandings and preconceptions.

The learning cycle then affords a way for teaching to achieve self-regulation with respect to the formal version of the concept. Most earth science students are likely to have an understanding of temperature, pressure, atmosphere, and mineral as concrete concepts. Through exploration activities they can apply their understanding and also discover its limitations -- for instance, the difficulty of making quantitative predictions from pressure defined completely in terms of a barometer reading.

Here you will find some differences among your students, for some begin self-regulation much more quickly than others. For this reason you should make allowances in the amount of time available for experimentation by different students.

Please look back at the above concept list now, and do the following together with your partner: for each item that you classified on two or more levels, think of an activity that would bring out the shortcomings of the concrete version and thereby initiate self-regulation.

Review Questions

Please work on these items together with your partner.

1. Name two earth science concepts that can only be understood by use of formal reasoning patterns (i.e., they have no "concrete" version).

2. Name two earth science concepts for which you can identify two or more levels of meaning. Briefly define each level.

3. Select one of the concepts you have named in #1 or #2, or a concept mentioned earlier in this module, and briefly work out a learning cycle of exploration, concept introduction, and application that might be built around it.

4. Compare the learning activities that might be used for a "formal concept" with those that might be appropriate for a "concrete" concept (or the concrete version of the same concept).

MODULE 7
CONCRETE AND FORMAL CONCEPTS

Introduction

Many chemistry teachers think about their courses in terms of topics covered, concepts explained, and principles applied. Our effort in this workshop has been to call your attention to another important dimension of chemistry teaching, your students' patterns of reasoning. By this time, you have probably concluded that many parts of a chemistry course are addressed to students who use formal reasoning patterns, and we would agree with that. Yet, there are students whose use of formal reasoning patterns is very limited. To help you reach more of your students, we suggest that you think about chemistry concepts according to the reasoning patterns necessary to understand the meaning you wish to communicate. Concepts may then be called "concrete" or "formal," in analogy to the stages of reasoning. When you plan your teaching, you can begin with "concrete" concepts and gradually progress to "formal" concepts. This module presents examples and explanations of "concrete" and "formal" concepts.

Objectives

To assist you in classifying chemistry concepts on the basis of the patterns of reasoning needed to understand them.

To assist you in sequencing instruction so as to encourage self-regulation.

Procedure

We have arranged this module in the form of a learning cycle built around the distinction between concrete and formal concepts. Please find a partner with whom you can join in the activities. Then undertake the activities described in the attached instructional materials. Proceed to Module 8 after you conclude the Review Questions.

Instructional Materials

1. Exploration

Below are five concepts introduced in many chemistry courses. Decide whether a student could develop an initial understanding of these concepts through (1) direct experience and the use of concrete reasoning patterns (classification, conservation, one-to-one correspondence) or (2) inferences from experience and formal reasoning patterns (reasoning with theories, models, and other concepts).

Begin by briefly describing to your partner some ways in which you would help your students understand each of the concepts listed. Then classify the concepts according to (1) or (2) above.

Chemical reaction:

Reaction rate:

Acid-base:

Chemical bond:

Ionization:

Please complete this activity and come to an understanding with your partner before continuing with the invention on the next page.

2. Concept Introduction: Concrete and Formal Concepts

In our opinion, "chemical reaction" and "acid-base" can readily be understood in terms of familiar actions, observations, and examples. In other words, these concepts can be derived from direct experience by using concrete reasoning patterns. Such concepts are called concrete concepts.

The concepts of "reaction rate," "chemical bond," and "ionization" must be understood in terms of other concepts (concentration, reaction time, atom, election, ion), inferences, and/or idealized models. These understandings are not the result of direct experiences and require application of formal reasoning patterns. Such concepts are called formal concepts.

Some concepts, of course, have more than one meaning and may, therefore, be "concrete" or "formal," depending on their treatment. Thus, temperature as read on a thermometer is a concrete concept; temperature as a measure of the average molecular kinetic energy is a formal concept. Before being classified, therefore, a concept must be defined clearly.

It may be good to mention at this time that the concrete vs. formal distinction is not equivalent to the familiar concrete vs. abstract distinction. All concepts are abstract, abstracted from many specific instances and conctete examples.

"Acid" is abstract in that it is general, applicable to many substances that taste sour, turn litmus paper red, and exhibit certain other properties. Since numerous direct experiences are readily available to illustrate this meaning of acid, acid, in this sense (not as a proton donar), is a "concrete" concept and has been taught successfully to elementary school children.

The reaction rate concept is also abstract, yet its meaning depends on an understanding of chemical equations, stoichiometric relations, and concentration change per unit time. These can be grasped only through propositional reasoning, making inferences from postulates about the reaction mechanism, functional relationships, abstract variables, idealized models, and other formal reasoning patterns.

The analysis of concepts is, of course, not exhausted by the point we have raised above. We realize, also, that some educators use the term concept with a somewhat different significance than we have given it. We believe, however, that our distinction between concrete and formal concepts can be applied beneficially without detailed examination of these other issues.

3. Concept Application

To allow you to apply your present understanding of the distinction between "concrete" and "formal" concepts, we have constructed a list of items we should like you to classify. Discuss each item with your partner to help you clarify your ideas, but record your own views if you two disagree. To help you justify your classifications, we have included here a slightly edited version of the concrete and formal reasoning patterns originally given in Module 2.

The concrete reasoning patterns most frequently required for the understanding of chemistry concepts are:

C1. understands concepts defined in terms of familiar actions and examples that can be observed directly;

C2. applies conservation reasoning to objects;

C3. establishes one-to-one correspondences and arranges data in increasing or decreasing sequence;

C4. makes simple classifications and successfully relates systems to subsystems, classes to subclasses.

The formal reasoning patterns most frequently required for the understanding of chemistry concepts are:

F1. understands concepts defined in terms of other concepts or through abstract relationships such as ratios or mathematical limits;

F2. imagines all possible combinations of conditions even though not all may be realized in nature;

F3. separates the effects of several variables by varying only one at a time;

F4. uses theories or idealized models;

F5. recognizes and applies functional relationships, such as direct and inverse proportion;

F6. understands the nature of probability and recognizes its implications for experimental design and data analysis.

The differences between these reasoning patterns might be summarized as follows: the concrete patterns apply simple operations to real objects and experiences, but not to relationships, hypothesized objects, or postulated properties. A concept can usually be considered "concrete," therefore, if one can grasp its meaning through direct experience. If a concept derives its meaning principally from its position within a theoretical system, it has to be classified as "formal."

Here are the concepts for your exercise. We have included answers for the first two items to illustrate how you might refer to the above lists of reasoning patterns when you give your reasons.

	Concept	C or F	Reasons
1.	Pressure	C	Defined operationally through a barometer reading, with pressure differences defined by a manometer (C1). Pressures can be compared (C3).
		F	The usual definition, force per unit area, depends on the force concept (F1) and on proportions (F5). Pressure can be use to calculate gas volumes or forces exerted on container surfaces.
		F+	Pressure is the time-average effect of molecular bombardment of the containing surface (F1, F4, F5). This concept derives its meaning from the kinetic-molecular theory, a theoretical system in modern physics.
2.	Periodic system of elements	C	Depends upon observable similarities and differences of elements, simple classification, one-to-one correspondences, and serial ordering (C1, C3, and C4). The fact that only some of the elements can actually be examined in the classroom does not alter this conclusion, in our opinion, since many important examples can be observed.
		F+	The relation between electron number, quantum numbers of electronic states in atoms, the Pauli exclusion principle, and position in the periodic table requires the understanding of concepts defined in terms of other concepts (F1), imagining combinations of conditions (F2), and using theories (F3).
3.	Temperature		
4.	Reaction heat		

5. Concentration

6. Phase of matter

7. Oxidation-reduction reaction

8. Chemical equation

Recall that the student who uses primarily concrete reasoning patterns does not reason beyond concrete objects, events, or experiences, has little power of reflection, and does not construct theoretical systems. Hearing a lecture or reading about reaction rates, chemical bonds, ionization or other formal concepts will not provide such a student with the necessary background of experience to understand these concepts. Instead, instruction should begin with exploratory experiences and "concrete" concepts.

The fact that some chemistry concepts can be interpreted either as "concrete" or "formal" helps in finding a teaching procedure that may lead to self-regulation. Learning that begins with a concrete version of a concept is likely to make a more secure connection with the student's previous understandings and preconceptions.

The learning cycle then affords a way for teaching to achieve self-regulation with respect to the formal version of the concept. Most chemistry students are likely to have an understanding of temperature, solution, concentrations, and reaction as "concrete" concepts. Through exploration activities they can apply their understanding and also discover its limitations -- for instance, the difficulty of making quantitative predictions from concentration defined completely in terms of the darkness in color of a solution.

Here you will find some differences among your students, for some begin self-regulation much more quickly than others. For this reason you should make allowances in the amount of time available for experimentation by different students.

Please look back at the above concept list now, and do the following together with your partner: for each item that you classified on two or more levels, think of an activity that would bring out the shortcomings of the concrete version and thereby initiate self-regulation.

Review Questions

Please work on these items together with your partner.

1. Name two chemistry concepts that can only be understood by use of formal reasoning patterns (i.e., they have no "concrete" version).

2. Name two chemistry concepts for which you can identify two or more levels of meaning. Briefly define each level.

3. Select one of the concepts you have named in #1 or #2, or a concept mentioned earlier in this module, and briefly work out a learning cycle of exploration, concept introduction, and application that might be built around it.

4. Compare the learning activities that might be used for a "formal" concept with those that might be appropriate for a "concrete" concept (or the concrete version of the same concept).

MODULE 8
TESTS AND SELF-REGULATION

Introduction

Effective use of tests allows you to evaluate the development of student reasoning and to provide additional opportunities for self-regulation. This module contains examples of concrete and formal test items as well as suggestions of how to use these items as part of the learning cycle.

Objectives

To assist you in recognizing, selecting, and designing test items that will be helpful in (1) evaluating student understanding and reasoning patterns and (2) encouraging self-regulation.

Procedure

Begin with the exploration activity starting the instructional materials. Then read the essays on concrete and formal test items and on using tests to encourage self-regulation. Join with your partner or group to classify the test items in the application section of the module as either concrete or formal. Finally, design two test items, one that makes use of concrete reasoning patterns and one that requires formal thought. We suggest that you conclude the module with a more general discussion of the issues raised here as as well as your particular test items. Then proceed to Module 9 in Part III.

Instructional Materials

1. Exploration

Below are four physics test items followed by a few student responses. Read each item and think how you would respond. Even if you do not know the answers (that is not important), think about what information you would need and what reasoning patterns you would use to solve the problems. On the basis of what you have learned to this point, classify the problems as requiring either (1) concrete or (2) formal patterns of reasoning for complete solution without guessing. Our classification will follow.

Item 1 During part of an automobile race, four cars were timed as they travelled around the track. Please arrange the cars in order from the fastest to the slowest, given the following data:

Student A

Car A takes 85 seconds for two laps. Fastest: C

Car B takes 125 seconds for three laps. 84 sec Second: D

Car C takes 70 seconds for two laps. Third: B

Car D takes 74 seconds for two laps. Fourth: A

Please explain how you found your answer.

$$\frac{125}{3} = \begin{array}{r} 42 \\ 3\overline{)125} \\ \underline{12} \\ \underline{05} \\ 20 \end{array}$$

I determined the two lap travel of B. Then I arrange the cars in order of two lap time.

Student B

Car A takes 85 seconds for two laps. $\frac{85}{2} \approx 42 \frac{sec}{lap}$ Fastest: C

Car B takes 125 seconds for three laps. $\frac{125}{3} \approx 41 \frac{sec}{lap}$ Second: D

Car C takes 70 seconds for two laps. $35 \frac{sec}{lap}$ Third: B

Car D takes 74 seconds for two laps. $\frac{74}{2} = 37 \frac{sec}{lap}$ Fourth: A

Please explain how you found your answer.

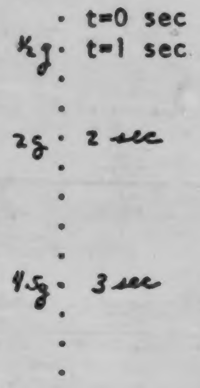
I divided the time by the number of laps done by that time

Item 2 An object falling from rest near the surface of the earth moves through the distance s in the time t. These variables are related by the equation $s = \frac{1}{2} gt^2$, where g is the acceleration of gravity. Circle the points where the particle will be at $t = 2$ sec and at $t = 3$ sec, given the marked points at $t = 0$ sec and $t = 1$ sec.

Student C

Please explain how you obtained your answers.

I found that each dot represents ½g when I plugged in t = 1sec into the formula. I then plugged 2 & 3 and found that s = 2g & 4.5g respectively.



Student D

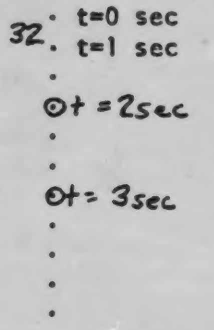
Please explain how you obtained your answers.

$s = \frac{1}{2} g 1^2$ $s = 32^2 2^2$

$\frac{g1}{2} = 1$ $\frac{1}{2} g 4$

$\frac{g4}{2} = g2$

$g 4.5$ $\frac{1}{2} \frac{g9}{2}$



Student E

Please explain how you obtained your answers.

$s = 0g$

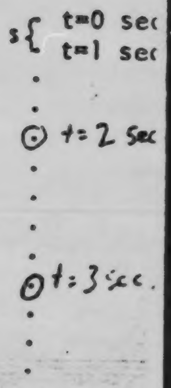
1 $s = \frac{1}{2} g(1) =$ $s_1 = \frac{1}{2} g$ $s = 1(\frac{1}{2} \cdot 2)$

2 $s = \frac{1}{2} g(4) =$ $s = 2g$

3 $s = \frac{1}{2} g(9) =$ $s = 4.5g$

$g = 2$

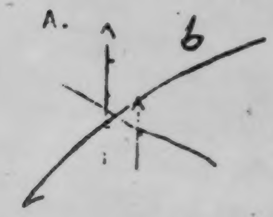
Substituted s and t in equation. For t = 1, I know that it traveled 1s, so by using equation with 1 variable (ex. for 1 sec, equation: s = ½) I can determine g to be two (2). Substitute 2 for g in remaining equations to find no. of "s" units traveled from start.



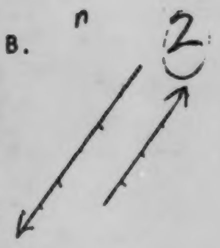
Item 3 Which of the following pairs of vectors has the resultant of the smallest magnitude?

Student F

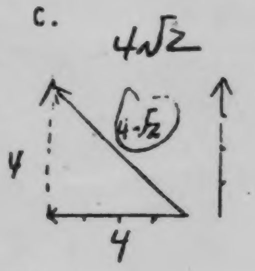
A.



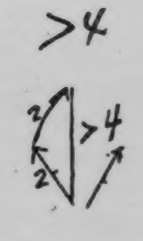
B.



C.



D.



Please explain how you found your answer.

A is obviously larger than D. D gives a resultant vector magnitude of >4 due to the triangle inequality theorem. C gives a resultant magnitude of $4\sqrt{2}$ due to Pythag's theorem. B gives a magnitude of 2 due to the cancelling action of the 2 vectors in antagonistic directions.

Student G

Please explain how you found your answer.

The first pair of vectors has the smallest magnitude, because the vectors are paraell to each other.

Student H

Please explain how you found your answer.

B - inspection of resultant vectors (found by placing origin of one at end of other and connecting of the other origin with the other end) made B's obviously shortest.

estimation of resultant vector magnitudes:

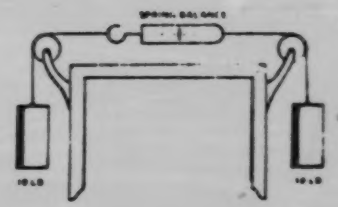
a - 6 units

B - 2 units

C. >5, < 6

D - 3

Item 4 The diagram shows two weights connected to a scale by strings passing over two pulleys. What is the reading of the scale?



Student I

A. 0 lb. B. 5 lb. C. 10 lb. D. 15 lb. [✓ E. 20 lb.]

Please explain how you found the answer.

The reading of the scale is 20 lbs. since each weight is pulling the spring in opposing directions ($\xleftarrow{10\text{ lbs}} + \xrightarrow{10\text{ lbs}}$) so that the spring is being pulled apart with a force of 10+10 or 20 lb

Student J

[✓ A.] 0 lb. B. 5 lb. C. 10 lb. D. 15 lb. E. 20 lb.

Please explain how you found the answer.

The 10 lbs on each side cancel out each other.

Student K

[✓ A. 0 lb.] B. 5 lb. C. 10 lb. D. 15 lb. [✓ E. 20 lb.]

Please explain how you found the answer.

The two weights ~~cancel~~ add There are two forces on the string, one ~~o~~ one each end. Both forces are of equal magnitude. One is fectively pulling the spring balance up with a force of 10 lbs and the other is pulling the spring balance down with a force of 10 lbs. Thusly, 20 lbs. total

2. Concept Introduction: "Concrete and Formal Test Items"

We believe that test items can be classified as being concrete or formal, according to the reasoning patterns required to respond successfully without guessing. Using the patterns described in Module 2 and restated below in somewhat different form, we concluded that items 1 and 3 are concrete and items 2 and 4 are formal.

We categorize items as concrete if successful response requires the student to:

C1. recall facts;

C2. establish one-to-one correspondences between two sets of data, serial order a set of observations, or classify observations into groups;

C3. apply a memorized algorithm or formula;

C4. understand concepts defined in terms of familiar objects, events, and situations (concrete concepts).

We categorize items as formal if successful response requires the student to:

F1. reason hypothetically, i.e., with the form, if . . . then . . . therefore;

F2. apply theories or idealized models to interpret data;

F3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand a general necessity for the control of variables and recognize hidden assumptions;

F4. use combinatorial, proportional, algebraic, or probabilistic reasoning;

F5. understand and apply formal concepts, i.e., concepts that derive meaning through inferences from experience rather than through direct experience.

Item 1 was classified as concrete since it requires the student to establish a correspondence between time and speed (C2). Car B requires an adjustment of time by proportional reasoning, a formal pattern (F4). Students who do this successfully in the explanation, like Students A and B in our sample, show some evidence of formal thought in this respect.

Item 2 was classified as formal since it requires the application of an algebraic formula to an unusual graphical representation of the motion (F4). Note that Students C and F were successful, but Student D added increments of two and three spaces for the two-second and three-second points when he could not apply the algebra to the diagram.

Item 3 was classified as concrete because it can be solved by the simple algorithm of graphic vector addition (C3, C4), though the explanation may reveal formal thought by its thoroughness--Student F refers to the triangle inequality. Student G seems either not to know the algorithm or to have misunderstood "smallest magnitude" to mean largest.

Item 4 is formal again. It requires the student to supress the impulse toward using vector addition of forces and to apply the action-reaction principle instead (F1, F2, F5). Justifying how the correct answer of 10 lb. is derived can be difficult even for a physics teacher, and none of the students in our sample were able to solve this problem.

You may have noticed that the items required students to describe their reasons for the answer choice. We believe that asking students to justify their answers can be an important part of a test, a part the particularly emphasizes the use of reasoning patterns in an identifiable way as we explained above.

In view of these advantages, we strongly urge you to include a few test items that require justification and for which you allow more time -- possibly four to five minutes each. The questions we are using in this module have been adapted from frequently-used science tests by the addition of a request for justification. Don't use too many such items, they could create a severe grading problem as well as taking a relatively long time to answer.

You may be familiar with Bloom's method of classifying test items (B. S. Bloom [Ed.] , Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain, David McKay Company, New York, 1956). The relationship between Bloom's taxonomic levels and our concrete and formal classification scheme is of interest. Basically the Bloom taxonomy allows one to classify items into one of six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation.

In general, any item at the Knowledge level of the taxonomy would require only pre-operational or concrete reasoning patterns for successful response (C1). Although items on this level may involve abstract theories or idealized models, the student need only recall the names of such theories. He need not use them in a way that would imply that they were understood.

Items classified into the Comprehension or Application levels may require either concrete or formal thought depending upon the nature of the concept being assessed (see Module 7 for the distinction between concrete and formal concepts).

Test items on the Analysis, Synthesis, and Evaluation levels, which require elements such as

- recognizing unstated assumptions,
- checking consistency of hypothesis with given information and assumptions,
- comprehending interrelationships among ideas,
- comparing major theories and generalizations,

all involve formal reasoning patterns.

3. Using Test Items to Encourage Self-Regulation

How can knowledge of the reasoning processes involved in responding to test items help you use these items to encourage self-regulation? First, it should be clear that if your stated goals are to teach physics and provoke students to develop formal reasoning patterns, then you should not only encourage formal reasoning in the classroom or laboratory, you should also include some problems of this type on tests. Students quickly learn that test items reveal what a teacher really believes is important. It is, therefore, imperative for tests to include some items that challenge students' ability to reason formally. This line of argument, however, leads to a fundamental problem.

Unfortunately, since some students initially reason at the concrete level, a test with formal questions will include items that these students will almost certainly miss. The wrong thing to do, however, would be to eliminate this type of item completely. A line of attack more conducive to self-regulation and intellectual growth would be to (1) include a few formal items, (2) discuss the answers to these after the test, (3) discuss similar items during class time, (4) use some as thought-provoking homework assignments, and (5) award grades at least partially on the basis of improvement during the semester. In this way, students will learn that you indeed value critical and reflective thinking, and that you will reward this type of thinking where it really counts--on tests.

How can tests be designed to fit within the exploration-concept introduction-application learning cycle? In this workshop we have argued that instruction should be designed according to this sequence if it is to encourage self-regulation. That is, a period of exploration precedes concept introduction. Students are then given opportunities to apply the new concept to a variety of situations. Tests fit nicely into this learning cycle as part of the application phase if test items require reasoning patterns and concepts to be applied to new situations.

Suppose, for example, that laboratory and classroom activities invite the use of reasoning patterns required to understand controlled experimentation. The subsequent test should include a number of items that evaluate the extent to which students have become able to reason in this way. Not only should test items be included that refer to the materials used in the laboratory activities, but items involving new and unfamiliar materials should also be included. These allow an evaluation of the extent to which the developing reasoning patterns can be generalized to new situations. It is our belief that formal reasoning patterns will become generally useful only after students have gradually reasoned through a wide variety of specific situations that invite the use of formal thought. Test items, if used properly, can aid this process.

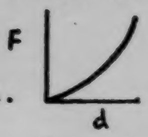
In summary, test items should not only evaluate specific knowledge, they should evaluate concrete and formal conceptual understanding, and they should evaluate the extent to which concrete and formal reasoning patterns have been developed and are generalized. In this way tests will serve both as a means of evaluation and also as valuable learning experiences that can significantly aid the self-regulation process.

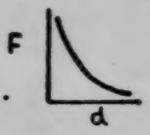
4. Concept Application

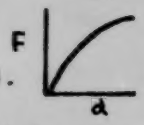
To provide you with additional experience, join with your partner to classify the following test items into concrete or formal types. Use the clues we have provided together with any criteria you have developed. Please write your answers and reasons in the space provided. (We suggest that you not spend time solving difficult problems now.)

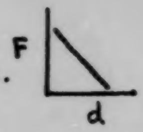
Item 5

Newton's Law of Gravitation is expressed as $F = G\frac{Mm}{d^2}$ where F is the force, M and m are two masses, G is a constant, and d represents the distance between the two masses. Assuming that M and m as well as G remain the same, which of the following graphs shows how the force changes when the distance between the masses varies?[1]

A.


*C.


B.


D.


Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 to F5).

Item 6

What is the displacement of a car that travels at a steady speed of 40 km/hour for three hours on a straight road?

(a) 43 km
(b) 120 km
(c) 13.3 km
(d) need more information

Please explain your choice

(Circle one) Concrete Formal

Your reasons (please refer to C1 to F5).

---

[1] Bloom, Taxonomy, p. 102.

Item 7

Galileo investigated the problem of the acceleration of falling bodies by rolling balls down very smooth planes inclined at increasing angles, since he had no means of determining very short intervals of time. From the data obtained he extrapolated for the case of free fall. Which of the following is an assumption implicit in the extrapolation?

1. That air resistance is negligible in free fall.
2. That objects fall with constant acceleration.
3. That the acceleration observed with the inclined plane is the same as that involved in free fall.
4. That the planes are frictionless.
5. That a vertical plane and one which is nearly so have nearly the same effect on the ball.[2]

Explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 8

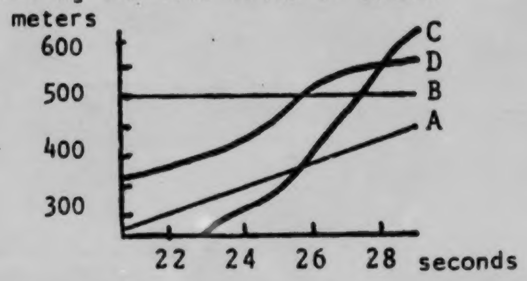
The graph shows positions of four cars during part of a race. Which car has a displacement of zero during the time interval shown?

(a) car A

(b) car B

(c) car C

(d) car D



Explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

---

[2] Bloom Taxonomy, p. 151.

Item 9

A capacitor and resistor are connected in a circuit as shown in Fig. 2. The values are $C = 250\ \mu\mu f$, $R = 10\ 000\Omega$, and $E = 400$ V. Initially the switch is closed and then it is opened suddenly. Use two methods to calculate the energy dissipated in the resistor after the switch is opened. Do both methods give the same result? Should they give the same result? If so, why? If not, why not?

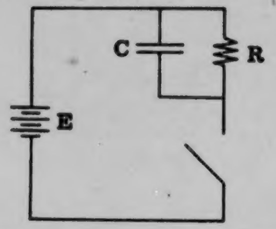


Fig. 2.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

After discussing your classification of the above test items, write one original test item that requires concrete reasoning and one test item that requires formal reasoning. Join a discussion of these items, related issues raised in this module, and the discussion questions on the next page with other workshop participants and a workshop staff member.

Review Questions

1. Are open book tests a means of moving away from testing for recall of information and towards the evaluation of conceptual understanding and reasoning?

2. Do you think the ideas of mastery learning and retaking tests would be helpful in encouraging self-regulation?

3. Do you believe it would be reasonable to expect a student who initially reasons only at the concrete level to master formal subject matter? If not, how might you deal with such a situation?

4. How do you think your students would initially react to a shift away from recall type examinations to those that require conceptual understanding and formal reasoning? Why might this initial reaction be unfavorable? Be favorable?

5. For Item 9, what techniques or ideas would you include in a discussion following the test to provoke students to rethink their solutions?

Homework: Whether you use commercial test items or items prepared by yourself, the next time you give a test, identify the level of reasoning required to solve each problem. Think about student success or failure on these items in terms of reasoning.

MODULE 8
TESTS AND SELF-REGULATION

Introduction

Effective use of tests allows you to evaluate the development of student reasoning and to provide additional opportunities for self-regulation. This module contains examples of concrete and formal test items as well as suggestions of how to use these items as part of the learning cycle.

Objectives

To assist you in recognizing, selecting, and designing test items that will be helpful in (1) evaluating student understanding and reasoning patterns and (2) encouraging self-regulation.

Procedure

Begin with the exploration activity starting the instructional materials. Then read the essays on concrete and formal test items and on using tests to encourage self-regulation. Join with your partner or group to classify the test items in the application section of the module as either concrete or formal. Finally, design two test items, one that makes use of concrete reasoning patterns and one that requires formal thought. We suggest that you conclude the module with a more general discussion of the issues raised here as well as your particular test items. Then proceed to Module 9 in Part III.

Instructional Materials

1. Exploration

Below are four biology test items followed by a few typical student responses. Read each item and think about how you would respond. Even if you do not know the answers (that is not important), think about what information you would need and what reasoning patterns you would use to solve the problems. On the basis of what you have learned to this point, classify the problems as requiring either (1) concrete, or (2) formal patterns of reasoning for correct solution without guessing. Our classification will follow.

Item 1

Fifty pieces of various parts of plants were placed in each of five sealed containers of equal size. At the start of the experiment each jar contained 250 units of CO_2. The amount of CO_2 in each jar at the end of two days was as shown in the table.

Container	Plant	Plant part	Light Color	Temperature (°C)	CO_2 Remaining
1	Willow	leaf	blue	10	200
2	Maple	leaf	purple	23	50
3	Willow	root	red	18	300
4	Maple	stem	red	23	400
5	Willow	leaf	blue	23	150

On the basis of the data in the table, a fair test of the amount of CO_2 used per day at two different temperatures could be made by comparing which jars? ________________________

Please explain why you chose those jars.

Student A

34

The amount of CO2 rose under red lighting

Student B Willow 1; Maple 2; & Maple 4 Reason is that

~~[illegible] plant pots~~

I tried to pick out ~~[illegible]~~ variables that were different in each catogory.

Student C

1 and 5

Because both jars are exactly the same in everything but temp.

Student D

1 + 5

No. 1 is the lowest temperature. 10° + No. 5 has the highest temperature 23°.

Item 2

Four types of rats were bred for laboratory experiments. Type A rats were found to be more resistant to disease than Type C rats. Type B rats were less resistant to disease than Type C rats and Type D rats were more disease resistant than A rats. Which type of rats were least disease resistant? Explain your choice.

Student E

Type B because A was more than C
C was more than B
D was more than B
A was more than C but less than D
C was more than B. B would have to
be least diesease resistent

Student F

B. Because B were less than C
more than B & D more than
B & A more tha B

Student G

D. Because A was more than C and B
was less than C and D were more than
A so D was the most.

Item 3

In the early spring some chemical poison was dumped into a pond. It killed all the mold, bacteria, yeasts, and other types of decomposers. By the end of the summer members of the bass population of the pond began to die. The most likely reason for the bass deaths is:

(a) the poison that killed the decomposers also killed the bass;
(b) the bass had used the decomposers as a food source; since the food is no longer available the bass starved;
(c) bass ate the poisoned decomposers and poisoned themselves;
(d) the dead decomposers could no longer recycle nutrients so the productivity of the pond dropped to near zero.

Please explain your choice.

Student H A. after awhile the poisen was distributed throughtout the water and the bass couldnt get away from the poisen

Student I

D. mold, bacteria and yeasts produce nutrients into the water for the plants and sm animals to live and so the bass died of starvation

Student J

B. The lack of food would have no effect on the fish until the end of the summer when the suppley is scarce

Student K C. When it poisned the food + they ate they got some of the poisin + it killed them.

Item 4

In the city zoo there are 6 lions, 12 seals, 10 zebras, 6 bears, 535 birds, and 55 horses. Each of these is an example of:

(a) an ecosystem
(b) a food chain
(c) a biome
(d) a population

2. Concept Introduction: "Concrete and Formal Test Items"

We believe that test items can be classified as being concrete or formal, according to the reasoning patterns required to respond successfully without guessing. Using the patterns described in Module 2 and restated below in somewhat different form, we concluded that Items 1 and 3 are formal and Items 2 and 4 are concrete.

We categorize items as concrete if successful response requires the student to:

C1. recall facts;

C2. establish one-to-one correspondences between two sets of data, serial order a set of observations, or classify observations into groups;

C3. apply a memorized algorithm or formula;

C4. understand concepts defined in terms of familiar objects, events, and situations (concrete concepts).

We categorize items as formal if successful response requires the student to:

F1. reason hypothetically, i.e., with the form, if . . . then . . . therefore;

F2. apply theories or idealized models to interpret data;

F3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand a general necessity for the control of variables and recognize hidden assumptions;

F4. use combinatorial, proportional, or probabilistic reasoning;

F5. understand and apply formal concepts, i.e., concepts that derive meaning through inferences from experience rather than through direct experience.

Item 1 was classified as formal since it requires the student to recognize ambiguous and unambiguous experimental conditions, i.e., to understand what constitutes controlled experimental conditions (F3). Item 2 was classified as concrete since it requires the student only to serial order a set of observations (C2) and deal with familiar concepts such as disease (C4).

Item 3 was classified as formal since correct response implied an understanding of the relationships among the concepts of producers, decomposers, and consumers in the nutrient cycle of a pond ecosystem (F5). The item also involves drawing an inference based upon an understanding of these relationships (F1). Item 4 was considered to involve only concrete reasoning patterns since the concept of population can be understood in terms of experiences with familiar objects (C4).

You may have noticed that Items 1, 2, and 3 required students to describe their reasons for the answer choice. We believe that asking students to justify their answers can be an important part of a test, a part that particularly emphasizes the use of reasoning patterns in an identifiable way. Thus, if selection of the correct answer on Item 1 is justified without adequate reference to the experimental conditions ("Containers 1 and 5 because the researcher wanted to find out about willow leaves in blue light"), the student's understanding would be questionable. Conversely, a correct answer to Item 6 (listed below in discovery activity) with a thorough explanation of the way in which pH affects enzyme activity would be evidence of the use of formal reasoning patterns.

In view of these advantages, we strongly urge you to include a few test items that require justification and for which you allow more time -- possibly four to five minutes each. The questions we are using in this module have been adapted from frequently-used science tests by the addition of a request for justification. Don't use too many such items, they could create a severe grading problem as well as taking a relatively long time to answer.

You may be familiar with Bloom's method of classifying test items (B. S. Bloom [Ed.], Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain, David McKay Company, New York, 1956). The relationship between Bloom's taxonomic levels and our concrete and formal classification scheme is of interest. Basically the Bloom taxonomy allows one to classify items into one of six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation.

In general, any item at the Knowledge level of the taxonomy would require only pre-operational or concrete reasoning patterns for successful response (C1). Although items on this level may involve abstract theories or idealized models, the student need only recall the names of such theories. He need not use them in a way that would imply that they were understood.

Items classified into the Comprehension or Application levels may require either concrete or formal thought depending upon the nature of the concept being assessed (See Module 7 for the distinction between concrete and formal concepts).

Test items on the Analysis, Synthesis, and Evaluation levels, which require elements such as

- recognizing unstated assumptions,
- checking consistency of hypotheses with given information and assumptions,
- comprehending interrelationships among ideas,
- comparing major theories and generalizations,

all involve formal reasoning patterns.

3. Using Test Items to Encourage Self-Regulation

How can knowledge of the reasoning processes involved in responding to test items help you use these items to encourage self-regulation? First, it should be clear that if your stated goals are to teach biology *and* provoke students to develop formal reasoning patterns, then you should not only present students with problems that encourage formal reasoning in the classroom or laboratory, but you should also include some problems of this type on tests. Students quickly learn that test items reveal what a teacher really believes is important. It is, therefore, imperative for tests to include some items that challenge students' ability to reason formally. This line of reasoning, however, leads to a fundamental problem.

Unfortunately, since some students initially reason at the concrete level, such a test will include items that these students will almost certainly miss. The wrong thing to do, however, would be to eliminate this type of item completely. A line of attack more conducive to self-regulation and intellectual growth would be to (1) include a few formal items, (2) discuss the answers to these after the test, (3) discuss similar items during class time, (4) use some as thought-provoking homework assignments, and (5) award grades at least partially on the basis of improvement during the semester.

How can tests be designed to fit within the exploration-concept introduction-application learning cycle? In this workshop we have argued that instruction should be designed according to this sequence if it is to encourage self-regulation. That is, a period of exploration precedes concept introduction. Students are then given opportunities to apply the new concept to a variety of situations. Tests fit nicely into this learning cycle as part of the application phase if test items require reasoning patterns and concepts to be applied to new situations.

Suppose, for example, that laboratory and classroom activities invite the use of reasoning patterns required to understand controlled experimentation. The subsequent test should include a number of items that evaluate the extent to which students have become able to reason in this way. Item 1 mentioned above is a good example of such a question. Not only should test items be included that refer to the materials used in the laboratory activities, but items involving new and unfamiliar materials should also be included. These allow an evaluation of the extent to which the developing reasoning patterns can be generalized to new situations. It is our belief that formal reasoning patterns will become generally useful only after students have gradually reasoned through a wide variety of specific situations that invite the use of formal thought. Test items, if used properly, can aid in this process.

In summary, test items should not only evaluate specific knowledge, they should evaluate concrete and formal conceptual understanding, and they should evaluate the extent to which concrete and formal reasoning patterns have been developed and are generalized. In this way tests will serve both as a means of evaluation and also as valuable learning experiences that can significantly aid the self-regulation process.

4. Concept Application

To provide you with additional experience, join with your partner to classify the following test items into concrete or formal types. Use the clues we have provided together with any criteria you have developed. Please write your answers and reasons in the space provided. (We suggest that you not spend time solving difficult problems now.)

Item 5

In a population of butterflies, wing coloration is determined by one pair of alleles (W and w). The dominant allele makes up 60% of all the alleles in the population.

(a) How many different genotypes are there with respect to this characteristic?

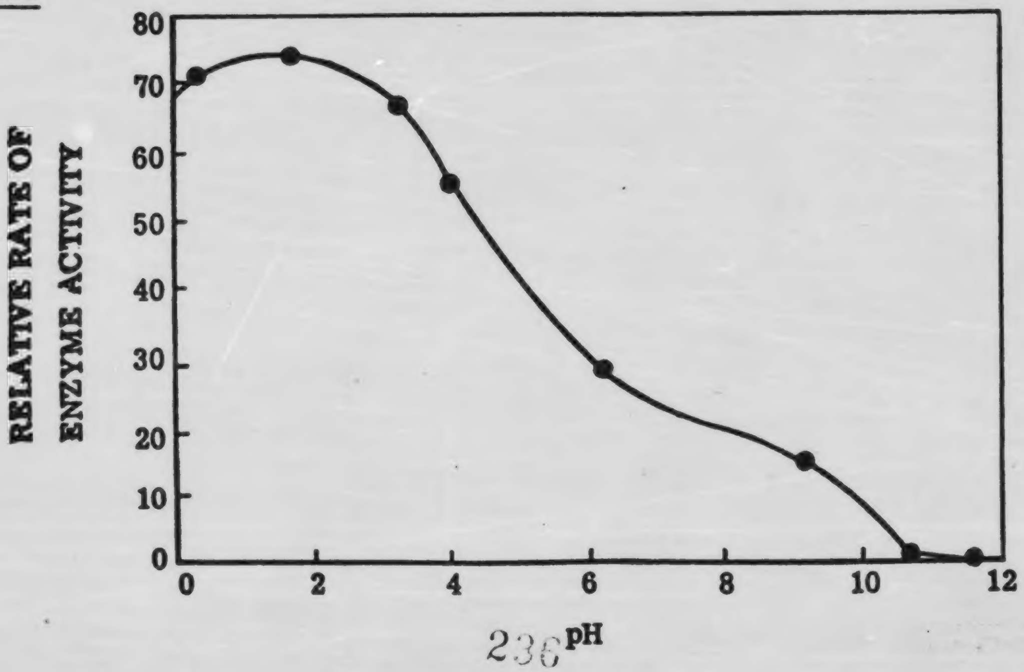
(b) What percentage of each is present in the population?

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 6



The enzyme graphed will work best in:

(a) an acid medium
(b) an alkaline medium
(c) a neutral medium
(d) a carbohydrate medium

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 7

The rate of oxidation in living cells is controlled by the action of:

(a) sugars
(b) enzymes
(c) fatty acids
(d) amino acids

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 8

A microscope has objective lenses of 10X and 50X power. Under high power, 95 evenly-distributed bacterial cells can be seen in the field of view. About how many cells can be seen in the field under low power? Remember that 10X means that the diameter of the field is magnified 10 times.

(a) 950
(b) 19
(c) 450
(d) 2400

Explain how you found your answer.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 9

Your biology teacher raises bean plants in a greenhouse. Sometimes his beans grow very tall in one month and sometimes they do not grow tall until four months. When you inspect his greenhouse you notice two types of fertilizer (high phosphate and low phosphate). You also notice some bean plants planted very close together and others planted over one foot apart. Further, some beans receive direct sunlight while others receive only artificial light. How could you research to find out the best way to raise large beans in only one month?

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

After discussing your classification of the above test items, write one original test item that requires concrete reasoning and one test item that requires formal reasoning. Join a discussion of these items, related issues raised in this module, and the discussion questions on the next page with other workshop participants and a workshop staff member.

Review Questions

1. Are open book tests a means of moving away from testing for recall of information and towards the evaluation of conceptual understanding and reasoning?

2. Do you think the ideas of mastery learning and retaking tests would be helpful in encouraging self-regulation?

3. Do you believe it would be reasonable to expect a student who initially reasons only at the concrete level to master formal subject matter? If not, how might you deal with such a situation?

4. How do you think your students would initially react to a shift away from recall type examinations to those that require conceptual understanding and formal reasoning? Why might this initial reaction be unfavorable? Be favorable?

5. Suppose you included Item 8 on a test. What techniques or ideas (or even materials) would you include in a discussion or activity about this item following the test?

Homework: Whether you use commercial test items or items prepared by yourself, the next time you give a test, identify the level of reasoning required to solve each problem. Think about student success or failure on these items in terms of reasoning.

MODULE 8
TESTS AND SELF-REGULATION

Introduction

Effective use of tests allows you to evaluate the development of student reasoning and to provide additional opportunities for self-regulation. This module contains examples of concrete and formal test items as well as suggestions of how to use these items as part of the learning cycle.

Objectives

To assist you in recognizing, selecting, and designing test items that will be helpful in (1) evaluating student understanding and reasoning patterns and (2) encouraging self-regulation.

Procedure

Begin with the exploration activity starting the instructional materials. Then read the essays on concrete and formal test items and on using tests to encourage self-regulation. Join with your partner or group to classify the test items in the application section of the module as either concrete or formal. Finally, design two test items, one that makes use of concrete reasoning patterns and one that requires formal thought. We suggest that you conclude the module with a more general discussion of the issues raised here as well as your particular test items. Then proceed to Module 9 in Part III.

Instructional Materials

1. Exploration

Below are four general science test items followed by a few typical student responses. Read each item and think about how you would respond. Even if you do not know the answers (that is not important), think about what information you would need and what reasoning patterns you would use to solve the problems. On the basis of what you have learned to this point, classify the problems as requiring either (1) concrete, or (2) formal patterns of reasoning for correct solution without guessing. Our classification will follow.

Item 1

Fifty pieces of various parts of plants were placed in each of five sealed containers of equal size. At the start of the experiment each jar contained 250 units of CO_2. The amount of CO_2 in each jar at the end of two days was as shown in the table.

Container	Plant	Plant part	Light Color	Temperature (°C)	CO_2 Remaining
1	Willow	leaf	blue	10	200
2	Maple	leaf	purple	23	50
3	Willow	root	red	18	300
4	Maple	stem	red	23	400
5	Willow	leaf	blue	23	150

On the basis of the data in the table, a fair test of the amount of CO_2 used per day at two different temperatures could be made by comparing which jars? ______________________

Please explain why you chose those jars.

Student A 3/4

The amount of Co2 rose under red lighting

Student B

1 + 5

No. 1 is the lowest temperature. 10° + No.5 has the highest temperature 23°.

Student C

1 and 5

Because both jars are exactly the same in everything but temp.

Student D

Willow 1; Maple 2; & Maple 4 Reason is that

[redacted]

I tried to pick out [redacted] variables that were different in each catogory.

1

Item 2

During part of an automobile race, four cars were timed as they traveled around the track. Please arrange the cars in order from the fastest to the slowest, given the following data:

Student E

Car A takes 85 seconds for two laps. Fastest: C

Car B takes 125 seconds for three laps. 84 sec Second: D

Car C takes 70 seconds for two laps. Third: B

Car D takes 74 seconds for two laps. Fourth: A

Please explain how you found your answer.

$\frac{125}{3} = 3\overline{)125.}$ 4 R
12
03
20

I determined the two lap travel of B. Then I arrange the cars in order of two lap time.

Student F

Car A takes 85 seconds for two laps. $\frac{85}{2} \approx 42 \frac{sec}{lap}$ Fastest: C

Car B takes 125 seconds for three laps. $\frac{125}{3} \approx 41 \frac{sec}{lap}$ Second: D

Car C takes 70 seconds for two laps. $35 \frac{sec}{lap}$ Third: B

Car D takes 74 seconds for two laps. $\frac{74}{2} = 37 \frac{sec}{lap}$ Fourth: A

Please explain how you found your answer.

I divided the time by the number of laps done by that time

Student G

Car A takes 85 seconds for two laps. 42.5 Fastest: C

Car B takes 125 seconds for three laps. 41.- Second: D

Car C takes 70 seconds for two laps. 35 Third: B

Car D takes 74 seconds for two laps. 37 Fourth: A

Please explain how you found your answer.

I divided the time by the number of la[illegible]
and then [illegible] how long it took e[illegible]
car [illegible]

Item 3

Four types of rats were bred for laboratory experiments. Type A rats were found to be more resistant to disease than Type C rats. Type B rats were less resistant to disease than Type C rats and Type D rats were more disease resistant than A rats. Which type of rats were least disease resistant? Explain your choice.

Student H

Type B because A was more than C
C was more than B
D was more than B
A was more than C but less than D
C was more than B. B would have to
be least diesease resistent

Student I

B. Because B were less than C
more than B & D more than
B & A more tha B

Student J

D. Because A was more than C and B
was less than C and D were more than
A so D was the most.

Item 4

A geologist finds a sandstone bed 1000 feet in thickness. He notes the size of the sand particles, and by studying the patterns of deposition, determines that the sandstone bed was deposited by stream action. He finds a stream which is carrying particles of the same size and which is depositing the particles in the same patterns. This stream deposits 1 foot of sand every ten years on the average. The geologist concludes that the sandstone bed was deposited over a period of at least 10,000 years. Which of the assumptions below, which the geologist made, is probably valid?

a. Streams carried particles in the past as they do today.
b. Particles being deposited today are similar to particles deposited in the past.
c. The deposition of the sandstone bed was continuous and constant.
d. Gravity and climate acted on streams in the past as they do today.
e. Three of the above are probably valid.

Please explain your choice.

Student K

c. Since he assumes the deposition of the sandstone bed was continuous and cons-te he can conclude how long of a period it took to deposite the sandstone bed

Student L

E. Because streams carried particles in the past as they do today, + Gravity + climate make changes in the depositi of Streams today + thousands of years ago.

C. The deposition of the sandstone is basically the same now as it was in the past.

Student M

ⓔ It states that he found sand particles of the same sizes in both streambeds. d - If the stream dried up - no water to flow + deposit sand. Gravity effects to a degree how much + how fast the sand particles will sink

2. Concept Introduction: "Concrete and Formal Test Items"

We believe that test items can be classified as being concrete or formal, according to the reasoning patterns required to respond successfully without guessing. Using the patterns described in Module 2 and restated below in somewhat different form, we concluded that Items 1 and 4 are formal and Items 2 and 3 are concrete.

We categorize items as concrete if successful response requires the student to:

C1. recall facts;

C2. establish one-to-one correspondences between two sets of data, serial order a set of observations, or classify observations into groups;

C3. apply a memorized algorithm or formula;

C4. understand concepts defined in terms of familiar objects, events, and situations (concrete concepts).

We categorize items as formal if successful response requires the student to:

F1. reason hypothetically, i.e., with the form, if . . . then . . . therefore;

F2. apply theories or idealized models to interpret data;

F3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand a general necessity for the control of variables and recognize hidden assumptions;

F4. use combinatorial, proportional, or probabilistic reasoning;

F5. understand and apply formal concepts, i.e., concepts that derive meaning through inferences from experience rather than through direct experience.

Item 1 was classified as formal since it requires the student to recognize ambiguous and unambiguous experimental conditions, i.e., to understand what constitutes controlled experimental conditions (F3). Item 2 was classified as concrete since it requires the student only to serial order times and establish a correspondence between time and speed. Can B requires an adjustment of time by proportional reasoning, a formal pattern (F4). Students who do this successfully in the explanation, like Students E and F, show some evidence of formal thought in this respect.

Item 3 was classified as concrete. Like Item 2, it requires the student to serial order a set of observations (C2) and deal with familiar concepts such as disease (C4).

Item 4 was considered formal in that it requires the student to recognize hidden assumptions (F3) and understand the geologists' currect application of an invalid assumption (F2, F3)! Notice that only student M seems to partially grasp this--"If the stream dried up - no water to flow and deposit sand."

You may have noticed that the items required students to describe their reasons for the answer choice. We believe that asking students to justify their answers can be an important part of a test, a part that particularly emphasizes the use of reasoning patterns in an identifiable way. Thus, if selection of the correct answer on Item 1 is justified without adequate reference to the experimental conditions ("Containers 1 and 5 because the researcher wanted to find out about willow leaves in blue light"), the student's understanding would be questionable. Conversely, a correct answer to Item 6 (listed below in discovery activity) with a thorough explanation of the way in which pH affects enzyme activity would be evidence of the use of formal reasoning patterns.

In view of these advantages, we strongly urge you to include a few test items that require justification and for which you allow more time -- possibly four to five minutes each. The questions we are using in this module have been adapted from frequently-used science tests by the addition of a request for justification. Don't use too many such items, they could create a severe grading problem as well as taking a relatively long time to answer.

You may be familiar with Bloom's method of classifying test items (B. S. Bloom [Ed.] , Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain, David McKay Company, New York, 1956). The relationship between Bloom's taxonomic levels and our concrete and formal classification scheme is of interest. Basically the Bloom taxonomy allows one to classify items into one of six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation.

In general, any item at the Knowledge level of the taxonomy would require only pre-operational or concrete reasoning patterns for successful response (C1). Although items on this level may involve abstract theories or idealized models, the student need only recall the names of such theories. He need not use them in a way that would imply that they were understood.

Items classified into the Comprehension or Application levels may require either concrete or formal thought depending upon the nature of the concept being assessed (See Module 7 for the distinction between concrete and formal concepts).

Test items on the Analysis, Synthesis, and Evaluation levels, which require elements such as

- recognizing unstated assumptions,
- checking consistency of hypotheses with given information and assumptions,
- comprehending interrelationships among ideas,
- comparing major theories and generalizations,

all involve formal reasoning patterns.

3. Using Test Items to Encourage Self-Regulation

How can knowledge of the reasoning processes involved in responding to test items help you use these items to encourage self-regulation? First, it should be clear that if your stated goals are to teach general science and provoke students to develop formal reasoning patterns, then you should not only present students with problems that encourage formal reasoning in the classroom or laboratory, but you should also include some problems of this type on tests. Students quickly learn that test items reveal what a teacher really believes is important. It is, therefore, imperative for tests to include some items that challenge students' ability to reason formally. This line of reasoning, however, leads to a fundamental problem.

Unfortunately, since some students initially reason at the concrete level, such a test will include items that these students will almost certainly miss. The wrong thing to do, however, would be to eliminate this type of item completely. A line of attack more conducive to self-regulation and intellectual growth would be to (1) include a few formal items, (2) discuss the answers to these after the test, (3) discuss similar items during class time, (4) use some as thought-provoking homework assignments, and (5) award grades at least partially on the basis of improvement during the semester.

How can tests be designed to fit within the exploration-concept introduction-application learning cycle? In this workshop we have argued that instruction should be designed according to this sequence if it is to encourage self-regulation. That is, a period of exploration precedes concept introduction. Students are then given opportunities to apply the new concept to a variety of situations. Tests fit nicely into this learning cycle as part of the application phase if test items require reasoning patterns and concepts to be applied to new situations.

Suppose, for example, that laboratory and classroom activities invite the use of reasoning patterns required to understand controlled experimentation. The subsequent test should include a number of items that evaluate the extent to which students have become able to reason in this way. Item 1 mentioned above is a good example of such a question. Not only should test items be included that refer to the materials used in the laboratory activities, but items involving new and unfamiliar materials should also be included. These allow an evaluation of the extent to which the developing reasoning patterns can be generalized to new situations. It is our belief that formal reasoning patterns will become generally useful only after students have gradually reasoned through a wide variety of specific situations that invite the use of formal thought. Test items, if used properly, can aid in this process.

In summary, test items should not only evaluate specific knowledge, they should evaluate concrete and formal conceptual understanding, and they should evaluate the extent to which concrete and formal reasoning patterns have been developed and are generalized. In this way tests will serve both as a means of evaluation and also as valuable learning experiences that can significantly aid the self-regulation process.

4. Concept Application

To provide you with additional experience, join with your partner to classify the following test items into concrete or formal types. Use the clues we have provided together with any criteria you have developed. Please write your answers and reasons in the space provided. (We suggest that you not spend time solving difficult problems now.)

Item 5

In a population of butterflies, wing coloration is determined by one pair of alleles (W and w). The dominant allele makes up 60% of all the alleles in the population.

(a) How many different genotypes are there with respect to this characteristic?

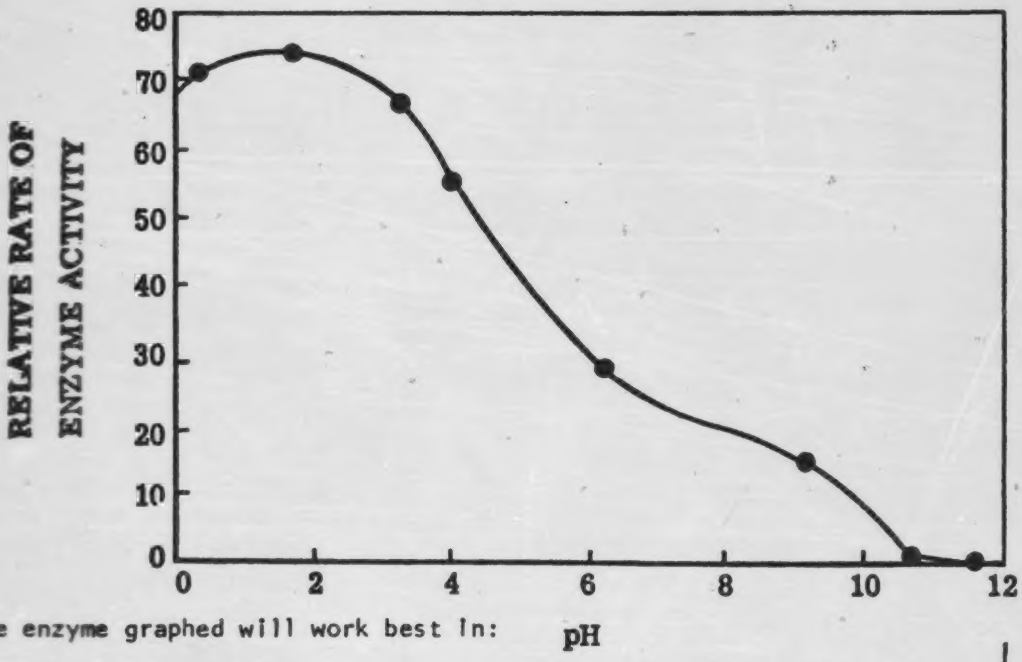
(b) What percentage of each is present in the population?

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 6



The enzyme graphed will work best in:

(a) an acid medium
(b) an alkaline medium
(c) a neutral medium
(d) a carbohydrate medium

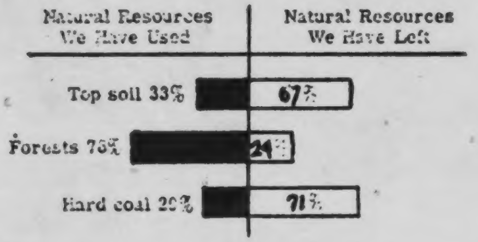
Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 7

The Taylor family spent their vacation at a lodge in a national park. The forest ranger showed the visitors at the lodge this graph:



The graph shows that we have nearly used up our

A. top soil
B. hard coal
C. forests
D. oil

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 8

What is the displacement of a can that travels at a steady speed of 40 km/hour for three hours on a straight road?

(a) 43 km
(b) 120 km
(c) 13.3 km
(d) need more information

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 9

The number of containers of chemicals that a laboratory can turn out varies directly as the time available and the number of chemists available. If ten chemists work 6 hours to produce 6 jars, how many containers can be turned out by 4 chemists working for 5 hours.

A. 2
B. 20
C. 4
D. 3

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5)

After discussing your classification of the above test items, write one original test item that requires concrete reasoning and one test item that requires formal reasoning. Join a discussion of these items, related issues raised in this module, and the discussion questions on the next page with other workshop participants and a workshop staff member.

Review Questions

1. Are open book tests a means of moving away from testing for recall of information and towards the evaluation of conceptual understanding and reasoning?

2. Do you think the ideas of mastery learning and retaking tests would be helpful in encouraging self-regulation?

3. Do you believe it would be reasonable to expect a student who initially reasons only at the concrete level to master formal subject matter? If not, how might you deal with such a situation?

4. How do you think your students would initially react to a shift away from recall type examinations to those that require conceptual understanding and formal reasoning? Why might this initial reaction be unfavorable? Be favorable?

5. Suppose you included Item 9 on a test. What techniques or ideas (or even materials) would you include in a discussion or activity about this item following the test?

Homework: Whether you use commercial test items or items prepared by yourself, the next time you give a test, identify the level of reasoning required to solve each problem. Think about student success or failure on these items in terms of reasoning.

MODULE 8
TESTS AND SELF-REGULATION

Introduction

Effective use of tests allows you to evaluate the development of student reasoning and to provide additional opportunities for self-regulation. This module contains examples of concrete and formal test items as well as suggestions of how to use these items as part of the learning cycle.

Objectives

To assist you in recognizing, selecting, and designing test items that will be helpful in (1) evaluating student understanding and reasoning patterns and (2) encouraging self-regulation.

Procedure

Begin with the exploration activity starting the instructional materials. Then read the essays on concrete and formal test items and on using tests to encourage self-regulation. Join with your partner or group to classify the test items in the application section of the module as either concrete or formal. Finally, design two test items, one that makes use of concrete reasoning patterns and one that requires formal thought. We suggest that you conclude the module with a more general discussion of the issues raised here as well as your particular test items. Then proceed to Module 9 in Part III.

Instructional Materials

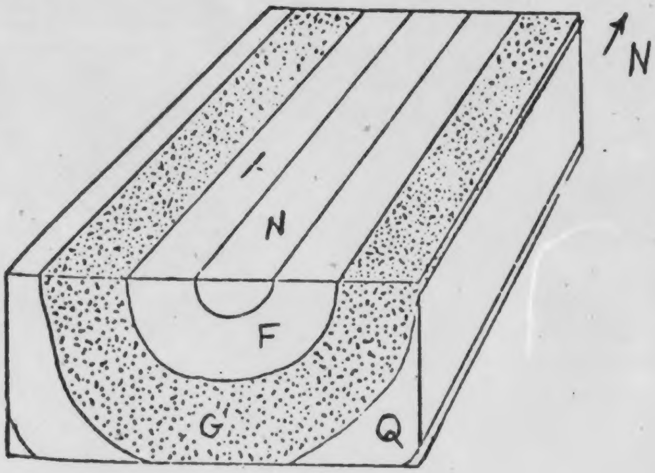
1. Exploration

Below are four earth science test items followed by a few typical student responses. Read each item and think about how you would respond. Even if you do not know the answers (that is not important), think about what information you would need and what reasoning patterns you would use to solve the problems. On the basis of what you have learned to this point, classify the problems as requiring either (1) concrete, or (2) formal patterns of reasoning for correct solution without guessing. Our classification will follow.

Item 1

Of the labeled beds of the block diagram on the right, the correct order from OLDEST to YOUNGEST is:

a. NFGQ
b. FQGN
c. QGFN
d. GNFQ



Please explain your choice.

Student A

The farthest beds downward are the oldest (except in some rare cases

Student B

Q was deposited many years ago, G was deposited after Q and so G is younger than Q, F was deposited after G and so its younger than G, N was deposited recently and so is the youngest of the sedimentary layers.

Student C

N7GQ

N is dust starting cause it is long and not as deep and as it it gets wider and longer that means it's older so 7 goes second cause its a little wider and so on

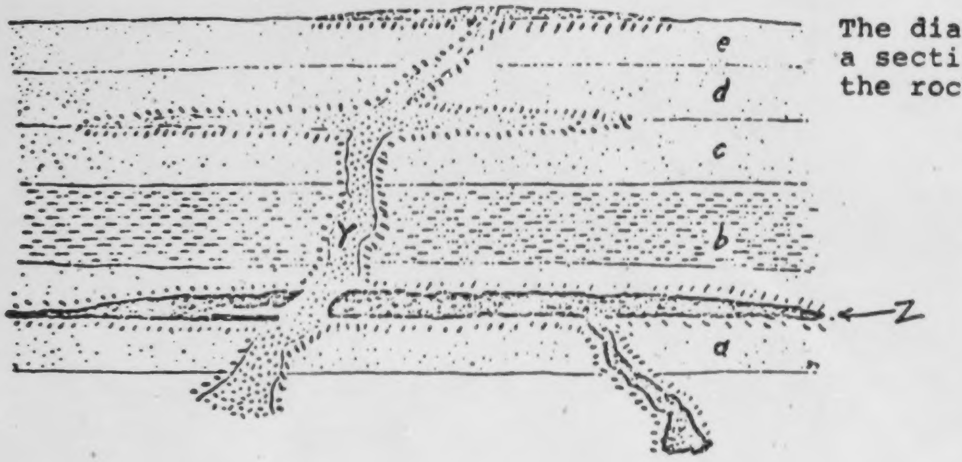
Student D

Ⓒ

The oldest material (Q) is on the bottom because it has settled down through the years. Sediments are layed upon each other, year after year and the newer material(N)'s on top. In time N will be covered by newer material.

Item 2

USE THE DIAGRAM AND DATA BELOW TO ANSWER THE NEXT QUESTION.



The diagram is a section through the rock layers.

DATA: a, b, c, d, and e are sedimentary beds.
Y and Z are igneous rocks.
All rocks adjacent to Y and Z appear to be chemically altered.
Y contains radioactive material which as been dated at 40 million years.
b contains igneous rock material which has been dated at 200 million years.

Which of the following statements is justified:

a. Rock c is younger than b and older than Z.
b. Rock b is younger than Z and older than a.
c. Rock a is older than Z and younger than Y.
d. Rock c is older than b and older than Z.
e. Rock Z is younger than a and older than Y.

Please explain your choice.

Student E

E. By logic. a is the farthest down so it's the oldest. Z is "higher" intruded into a after it had been found so it's younger than a. Since Y reached the surface through all beds it's much younger than Z.

Student F

E is pretty much a guess but a was the first sedimentary rock deposited and z is above a, so a might be older than a, and y could be the oldest because y has been locked up under ground for a long period of time and has been melted

Student G

(C). Rock C is younger because it is a higher level than Rock b.

Student H

"E" seems logical because the deeper the rock, the older it is.

Item 3

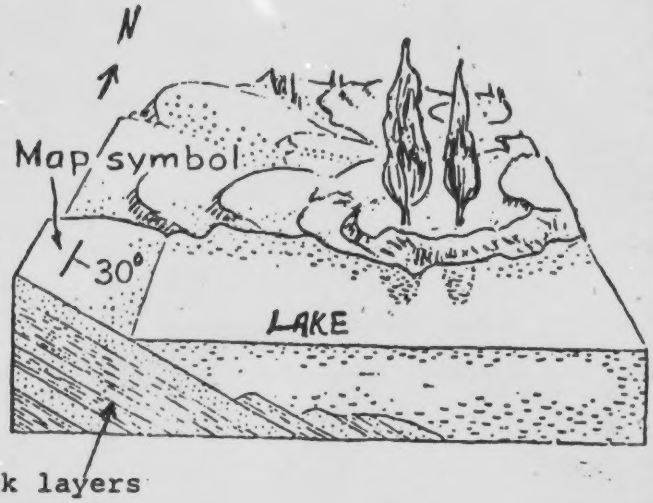
In geology, the term strike refers to the direction of a line formed by the intersection of rock layers with the horizontal plane. the term dip refers to the angle between rock layers and the horizontal plane.

Using the diagram, determine whether the rock layers

a. strike east and dip 30° west.

b. strike north and dip 30° west.
c. dip east and strike 30° north.

d. strike north and dip 30° east.



Please explain your choice.

Student I

b. West is always to your left.
The strike is north. ← (rather obvious)

Student J

d. because the stike run south to north and the dip is slanting 30° (towards th east)

Student K

Strike North

d. Based upon the definitions presented above, the line formed through the intersection of the rock strata with the surface of the lake, using said surface as the horizontal, runs in a northerly direction.
Dip 30° East. The angle, as indicated, is 30°. The downward slope runs east.

Item 4

A geologist finds a sandstone bed 1000 feet in thickness. He notes the size of the sand particles, and by studying the patterns of deposition, determines that the sandstone bed was deposited by stream action. He finds a stream which is carrying particles of the same size and which is depositing the particles in the same patterns. This stream deposits 1 foot of sand every ten years on the average. The geologist concludes that the sandstone bed was deposited over a period of at least 10,000 years. Which of the assumptions below, which the geologist made, is probably valid?

a. Streams carried particles in the past as they do today.
b. Particles being deposited today are similar to particles deposited in the past.
c. The depostion of the sandstone bed was continuous and constant.
d. Gravity and climate acted on streams in the past as they do today.
e. Three of the above are probably valid.

Please explain your choice.

Student L

C. Since he assumes the deposition of the sandstone bed was continuous and constant he can conclude how long of a period it took to deposite the sandstone bed

Student M

E. a Because streams carried particles in the past as they do today, + d Gravity + climate make changes in the deposi of Streams today + thousands of years ago.

C. The deposition of the ~~[illegible]~~ sandstone is basically the same now as it was in the past.

Student N

ⓔ It states that he found sand particles of the same sizes in both streambeds d - If the stream dried up - no waters to flow + deposit sand. Gravity effects to a degree how much + how fast the sand particles will sink.

2. Concept Introduction: "Concrete and Formal Test Items"

We believe that test items can be classified as being concrete or formal, according to the reasoning patterns required to respond successfully without guessing. Using the patterns described in Module 2 and restated below in somewhat different form, we concluded that Items 1 and 3 are concrete and Items 2 and 4 are formal.

We categorize items as concrete if successful response requires the student to:

C1. recall facts;

C2. establish one-to-one correspondences between two sets of data, serial order a set of observations, or classify observations into groups;

C3. apply a memorized algorithm or formula;

C4. understand concepts defined in terms of familiar objects, events, and situations (concrete concepts).

We categorize items as formal if successful response requires the student to:

F1. reason hypothetically, i.e., with the form, if . . . then . . . therefore;

F2. apply theories or idealized models to interpret data;

F3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand a general necessity for the control of variables and recognize hidden assumptions;

F4. use combinatorial, proportional, or probabilistic reasoning;

F5. understand and apply formal concepts, i.e., concepts that derive meaning through inferences from experience rather than through direct experience.

Item 1 was classified as concrete since it requires the student to recall the fact that older layers of sediment are deposited first (C2) and to serial order the observations (C2). Although the rock strata are not cement --they are concrete! (C4). Item 2 also involves serial ordering a set of observations (C2). Although the problem involves a much more complicated application of reasoning, it does not demand formal reasoning. The item is classified as concrete. If, however, the alternatives given the students were not so directive, the problem could require formal thought in that a careful analysis of combinations of layers and ages (F4) would be required.

Item 3 involves an understanding of the terms strike and dip. Although the terms may be unfamiliar, they refer to familiar ideas (C4). The item was considered concrete for this reason. Notice, however, that the student needs to imagine the horizontal plane and the subsequent 30° angle. This may tax the student's imagination and make the problem difficult, but it also does not necessarily involve formal reasoning. Item 4 was considered formal in that it requires the student to recognize hidden assumptions (F3) and understand the geologist's concept application of an invalid assumption (F2 and F3) ! Notice that only Student N seems to partially grasp this. "If the stream dried up--not water to flow and deposit sand."

You may have noticed that the items requested students to describe their reasons for the answer choice. We believe that asking students to justify their answers can be an important part of a test, a part that particularly emphasizes the use of reasoning patterns in an identifiable way. Thus, if selection of the correct answer on Item 4 is justified without adequate reference to the invalid assumption and the reason for its invalidity (note the response of Student M), then that student's understanding would be questionable.

In view of this advantage, we strongly urge you to include a few test items that require justification and for which you allow more time -- possibly four to five minutes each. The questions we are using in this module have been adapted from frequently-used science tests by the addition of a request for justification. Don't use too many such items, they could create a severe grading problem as well as taking a relatively long time to answer.

You may be familiar with Bloom's method of classifying test items (B. S. Bloom [Ed.] , Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain, David McKay Company, New York, 1956). The relationship between Bloom's taxonomic levels and our concrete and formal classification scheme is of interest. Basically the Bloom taxonomy allows one to classify items into one of six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation.

In general, any item at the Knowledge level of the taxonomy would require only pre-operational or concrete reasoning patterns for successful response (C1). Although items on this level may involve abstract theories or idealized models, the student need only recall the names of such theories. He need not use them in a way that would imply that they were understood.

Items classified into the Comprehension or Application levels may require either concrete or formal thought depending upon the nature of the concept being assessed (See Module 7 for the distinction between concrete and formal concepts).

Test items on the Analysis, Synthesis, and Evaluation levels, which require elements such as
- recognizing unstated assumptions,
- checking consistency of hypotheses with given information and assumptions,
- comprehending interrelationships among ideas,
- comparing major theories and generalizations,

all involve formal reasoning patterns.

3. Using Test Items to Encourage Self-Regulation

How can knowledge of the reasoning processes involved in responding to test items help you use these items to encourage self-regulation? First, it should be clear that if your stated goals are to teach earth science and provoke students to develop formal reasoning patterns, then you should not only present students with problems that encourage formal reasoning in the classroom, laboratory, or field, but you should also include some problems of this type on tests. Students quickly learn that test items reveal what a teacher really believes is important. It is, therefore, imperative for tests to include some items that challenge students' ability to reason formally. This line of reasoning, however, leads to a fundamental problem.

Unfortunately, since some students initially reason at the concrete level, such a test will include items that these students will almost certainly miss. The wrong thing to do, however, would be to eliminate this type of item completely. A line of attack more conducive to self-regulation and intellectual growth would be to (1) include a few formal items, (2) discuss the answers to these after the test, (3) discuss similar items during class time, (4) use some as thought-provoking homework assignments, and (5) award grades at least partially on the basis of improvement during the semester.

How can tests be designed to fit within the exploration-concept introduction-application learning cycle? In this workshop we have argued that instruction should be designed according to this sequence if it is to encourage self-regulation. That is, a period of exploration precedes concept introduction. Students are then given opportunities to apply the new concept to a variety of situations. Tests fit nicely into this learning cycle as part of the application phase if test items require reasoning patterns and concepts to be applied to new situations.

Suppose, for example, that laboratory and classroom activities invite the use of reasoning patterns required to understand controlled experimentation. The subsequent test should include a number of items that evaluate the extent to which students have become able to reason in this way. Not only should test items be included that refer to the materials used in the laboratory or field activities, but items involving new and unfamiliar materials should also be included. These allow an evaluation of the extent to which the developing reasoning patterns can be generalized to new situations. It is our belief that formal reasoning patterns will become generally useful only after students have gradually reasoned through a wide variety of specific situations that invite the use of formal thought. Test items, if used properly, can aid in this process.

In summary, test items should not only evaluate specific knowledge, they should evaluate concrete and formal conceptual understanding, and they should evaluate the extent to which concrete and formal reasoning patterns have been developed and are generalized. In this way tests will serve both as a means of evaluation and also as valuable learning experiences that can significantly aid the self-regulation process.

4. Concept Application

To provide you with additional experience, join with your partner to classify the following test items into concrete or formal types. Use the clues we have provided together with any criteria you have developed. Please write your answers and reasons in the space provided. (We suggest that you not spend time solving difficult problems now.)

Item 5

While panning for gold in a stream, you examine the particles of material in your gold pan and find feldspar and olivine crystals. You make the following inference because of your study of Geology:

(a) The particles are near their source area.

(b) The particles have been transported hundreds of miles from their source area.

(c) The sedimentary rocks upstream have been metamorphosed.

(d) There is no igneous rock upstream from your panning site.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 6

If the earth's axis of rotation were tilted so that it was always perpendicular to the rays of the sun, which of the following results would most likely occur?

(a) The lengths of days and nights would no longer vary.

(b) All water would eventually be trapped south of the equator.

(c) The United States would become too cold for habitation.

(d) The amount of solar energy would be drastically reduced.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 7

Which of the following is not a feature produced by deposition of glacial material?

(a) outwash plain

(b) medial morraine

(c) striation

(d) kame

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 8

Weathering processes on the moon:

(a) should be similar to those on the earth, assuming the principle of uniformity holds everywhere in the universe.

(b) should be more severe than those on earth due to the extreme temperature changes.

(c) should be quite different from those on earth due to the lack of free oxygen and water on the moon.

(d) should be similar to those on earth because the rocks on the moon are chemically and structurally very similar to those of the earth.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 9

A meandering river with steep valley walls and no flood plain would be considered:

(a) to be a young river
(b) to be a mature river.
(c) to be an old river
(d) to be a rejuvenated river.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

After discussing your classification of the above test items write one original test item that requires concrete reasoning and one test item that requires formal reasoning. Join a discussion of these items, related issues raised in this module, and the discussion questions on the next page with other workshop participants and a workshop staff member.

Review Questions

1. Are open book tests a means of moving away from testing for recall of information and towards the evaluation of conceptual understanding and reasoning?

2. Do you think the ideas of mastery learning and retaking tests would be helpful in encouraging self-regulation?

3. Do you believe it would be reasonable to expect a student who initially reasons only at the concrete level to master formal subject matter? If not, how might you deal with such a situation?

4. How do you think your students would initially react to a shift away from recall type examinations to those that require conceptual understanding and formal reasoning? Why might this initial reaction be unfavorable? Be favorable?

5. Suppose you included Item 6 on a test. What techniques or ideas (or even materials) would you include in a discussion or activity about this item following the test?

Homework: Whether you use commercial test items or items prepared by yourself, the next time you give a test, identify the level of reasoning required to solve each problem. Think about student success or failure on these items in terms of reasoning.

MODULE 8
TESTS AND SELF-REGULATION

Introduction

Effective use of tests allows you to evaluate the development of student reasoning and to provide additional opportunities for self-regulation. This module contains examples of concrete and formal test items as well as suggestions of how to use these items as part of the learning cycle.

Objectives

To assist you in recognizing, selecting, and designing test items that will be helpful in (1) evaluating student understanding and reasoning patterns and (2) encouraging self-regulation.

Procedure

Begin with the exploration activity starting the instructional materials. Then read the essays on concrete and formal test items and on using tests to encourage self-regulation. Join with your partner or group to classify the test items in the application section of the module as either concrete or mal. Finally, design two test items, one that makes use of concrete reasoning patterns and one that requires formal thought. We suggest that you conclude the module with a more general discussion of the issues raised here as well as your particular test items. Then proceed to Module 9 in Part III.

Instructional Materials

1. Exploration

Below are four chemistry test items followed by a few typical student responses. Read each item and think about how you would respond. Even if you do not know the answers (that is not important), think about what information you would need and what reasoning patterns you would use to solve the problems. On the basis of what you have learned to this point, classify the problems as requiring either (1) concrete, or (2) formal patterns of reasoning for correct solution without guessing. Our classification will follow.

Item 1

According to the kinetic theory, the rate of diffusion of a high molecular weight gas is slower than the rate of diffusion of a low molecular weight gas. Which of the following can you conclude?

A. Perfume vapor with a molecular weight of 360 will be smelled before onion vapor with a molecular weight of 720 if both are released at the same time and place.

B. The higher the molecular weight of a gas, the sooner an equilibrium state is reached in a closed system.

C. Onion vapor is more offensive than perfume vapor.

D. Perfume vapor with a molecular weight of 360 will be smelled after onion vapor with a molecular weight of 720 if both are released at the same time and place.

Please explain briefly what is wrong with the other choices.

Student A - student selected A.

B. has nothing to do with what is explained in the question
C - Even though one already knows this it can't be conclude
from the information given in the question
D-- It is exactly the reverse of what the question says

Student B - student selected A.

B. an equillbrium might not be reached if it is a closed system for any gas no matter what the weight is.

C. It depends on the person. one person might like the smell of onions and one might not.

D. according to the statement above the high molecular weighted gas diffuses slower than the low molecular weighted gas.

Student C - student selected C.

A. ONION VAPOR WELL smelled AT THE SAME TIME AS PERFUME ONLY ONION VAPOR will be STRONGER

B. Lower molecular weight of a gas, sooner equilibrium

D. Both will be smelled AT SAME TIME.

Student D - student selected A.

C. Is wrong because it has a higher molecular weight + takes longer to diffuse

D is wrong because the onion ~~weight~~ molecular weight is more than that of perfume

B is wrong because the higher the molecular weight the longer it takes for a gas to reach an equilibrium.

Item 2

More precisely, the relative rates of diffusion of two gases under ideal conditions are inversely proportional to the square roots of their molecular weights. In a test comparing diffusion of onion vapor (molecular weight 720) and perfume vapor (molecular weight 360), the onion vapor is detected about six seconds after its release. How long after release would you expect perfume vapor to be detected?

A. 3 seconds B. 4 seconds C. 6 seconds D. 9 seconds E. 12 seconds

Please explain how you found the answer.

Student E

I set up a proportion of the rate of diffusion
(given) over the molecular weight
of that substance: $\frac{6}{720} = \frac{x}{360}$
6 seconds is to 720 (molecular weight of onion) as
x is to 360. 6 X 360 = 2160 I then
divided 2160 by 720 (molecular weight of
perfume) and came out with $\boxed{\text{3 seconds}}$

Student F

It was mostly a guess but
720 = 6 × 120 and
360 = 3 × 120 so since
difussion of onion vapor = 6 seconds
then maybe the diffusion of
perfume vapor might = $\boxed{\text{3 seconds}}$

Student G

Since they are inversely proportional
and 720 is 2(360) and the onion
vapor is detected about 6 seconds
after it is released the perfume
vapor would have to be
detected in 2(6) seconds or $\boxed{\text{12 sec.}}$

Item 3

How many atoms are in one molecule of the substance

$(NH_4)_2TiO(C_4O_4)_2 \cdot H_2O$?

Please show your calculation.

Student H

2 N
8 H
1 Ti
1 O
8 C
8 O
2 H
1 O

31 atoms

Student I

$\overset{5}{(NH_4)_2}$ $\quad T_iO \quad (C_4O_4)_2 \quad \cdot H_2O$

↓ ↓ ↓ ↓ ↓

$\cancel{N_{2N}H_8}$ $\quad 1(T_i)1(O) \quad 2(C_4)\ 2(O_4) \quad 2(H)+O$

$2(N)+2(H_4)\cancel{2(NH_4)}$

↓ ↓ ↓ ↓

$2(N)+8(H)+1(T_i)+1(O)+8(C)+8(O)+2(H)+(O)$

$2+8+1+1+8+8+2+1 = \underline{31}$ atoms/molecule

Student J

$$\begin{array}{r}13\\16\\\hline 29\end{array}$$

(NH_4)
NH_4
Ti
O
C_4^2
O_4^2
H_2
O

Student K

$(NH_4)_2$ = 10 ATOMS
$(C_4O_4)_2$ = 16 ATOMS
$T_1 + O + H_2 + O$ = 5 ATOMS

31 ATOMS

4

Balance this equation involving the new elements X and Z:

$2\ H_2XO_3 + (\underline{A})\ H_3ZO_3 \rightarrow (\underline{B})\ HX + (\underline{C})\ H_3ZO_4 + (\underline{D})\ H_2O$

The coefficient (C) is

A. 1 [✓ B. 2] C. 3 D. 4 E. 5

Please explain your choice.

Student L

$2H_2XO_3 + \_\ H_3ZO_3 \rightarrow 2HX + \_\ H_3ZO_4 + \_\ H_2O$

2 × 2H

2X2H

$2H\,XO_3 + \underline{2}\ H_3ZO_3 \longrightarrow \cancel{2}\ \underline{2}\ H_3ZO_4 + \underline{1}\ H_2O$

$2H_2XO_3 + 2H_3ZO_3 \longrightarrow 2HX + 2H_3ZO_4 + H_2O$

Student M A. 1 B. 2 C. 3 D. 4 [✓ E. 5] 1'

A=5 B=2

C=5 D=

Please explain your choice.

~~[illegible]~~ B had tobe 2 because there were only 2 X's i

the first one

A & C had to be

the same beca

of the Zs.

10 10

3

13

19 19

12

10 H

Student N A. 1 [✓ B. 2] C. 3 D. 4 E. 5

to balance the O the C has to be a three

Please explain your choice.

$4H + 1H_3 \rightarrow 2H + 1H_3 + 1H_2$ ✓

$2O_3 + 1O_3 \rightarrow X + 1O + \_\ O$

$2X + \cancel{1X\,Z} \rightarrow 2X\ \ 3X$

$\_\ Z \cdot 1\ \ X \rightarrow \cancel{X} +$

$2X + \cancel{Z} \rightarrow 2X$

$2H_2XO_3 + \overset{3}{\cancel{2}}H_3ZO_3 \rightarrow 2HX + \overset{3}{\cancel{2}}H_3ZO_4 + 1H_2O$ H✓

$1H_2XO_3 + 2H_3ZO_3 \rightarrow 1HX + 2H_3ZO_4 + H\ O$

2. Concept Introduction: "Concrete and Formal Test Items"

We believe that test items can be classified as being concrete or formal, according to the reasoning patterns required to respond successfully without guessing. Using the patterns described in Module 2 and restated below in somewhat different form, we concluded that Items 1 and 3 are concrete and Items 2 and 4 are formal.

We categorize items as concrete if successful response requires the student to:

C1. recall facts;

C2. establish one-to-one correspondences between two sets of data, serial order a set of observations, or classify observations into groups;

C3. apply a memorized algorithm or formula;

C4. understand concepts defined in terms of familiar objects, events, and situations (concrete concepts).

We categorize items as formal if successful response requires the student to:

F1. reason hypothetically, i.e., with the form, if . . . then . . . therefore;

F2. apply theories or idealized models to interpret data;

F3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand a general necessity for the control of variables and recognize hidden assumptions;

F4. use combinatorial, proportional, or probabilistic reasoning;

F5. understand and apply formal concepts, i.e., concepts that derive meaning through inferences from experience rather than through direct experience.

Although a good understanding of the kinetic theory certainly depends on formal thought, Item 1 was classified as concrete because it requires the student only to serial order the given data (C2). Two inversions from the given data are needed, however -- high weight → slow rate and slow rate → long time -- which ultimately lead to a direct correspondence, lower weight → shorter time. Item 2, on the other hand, requires the student to apply an inverse square-root relationship, a formal reasoning pattern (F4). None of the student responses on page 8-4 is correct. The factoring strategy used by Student F is evidence of concrete reasoning.

Item 3 was classified as concrete since the correct response involves merely recalling certain facts and well-defined rules regarding chemical formulas (C1) and using them to manipulate symbols (C3). Item 4 was classified as formal since it requires a systematic overall approach to analysis and comparison of the various combinations and possibilities (F4). It also requires deductive reasoning, as in "(B) has to be 2 because there are two atoms of X, A = C because of conservation of Z atoms," and so on (see Student M). The students who were answering had not yet learned about oxidation-reduction reactions and the balancing of ionic charges.

You, no doubt, have noticed that the items asked students to describe their reasons for the answer choice. We believe that asking students to justify their answers can be an important part of a test, a part that particularly emphasizes the use of reasoning patterns in an identifiable way. Thus, if selection of the correct answer on Item 4 is only partially justified, as was the case for Student M, the student's reasoning can be probed further to find and if the correct answer was in part a lucky guess or was the result of formal reasoning.

Conversely, although Item 1 requires only concrete reasoning for success, an analysis of the student's responses could indicate the use of formal reasoning.

In view of these advantages, we strongly urge you to include a few test items that require justification and for which you allow more time -- possibly four to five minutes each. The questions we are using in this module have been adapted from frequently-used science tests by the addition of a request for justification. Don't use too many such items, they could create a severe grading problem as well as taking a relatively long time to answer.

You may be familiar with Bloom's method of classifying test items (B. S. Bloom [Ed.] , Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain, David McKay Company, New York, 1956). The relationship between Bloom's taxonomic levels and our concrete and formal classification scheme is of interest. Basically the Bloom taxonomy allows one to classify items into one of six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation.

In general, any item at the Knowledge level of the taxonomy would require only pre-operational or concrete reasoning patterns for successful response (C1). Although items on this level may involve abstract theories or idealized models, the student need only recall the names of such theories. He need not use them in a way that would imply that they were understood.

Items classified into the Comprehension or Application levels may require either concrete or formal thought depending upon the nature of the concept being assessed (See Module 7 for the distinction between concrete and formal concepts).

Test items on the Analysis, Synthesis, and Evaluation levels, which require elements such as

- recognizing unstated assumptions,
- checking consistency of hypotheses with given information and assumptions,
- comprehending interrelationships among ideas,
- comparing major theories and generalizations,

all involve formal reasoning patterns.

3. Using Test Items to Encourage Self-Regulation

How can knowledge of the reasoning processes involved in responding to test items help you use these items to encourage self-regulation? First, it should be clear that if your stated goals are to teach chemistry and provoke students to develop formal reasoning patterns, then you should not only present students with problems that encourage formal reasoning in the classroom or laboratory, but you should also include some problems of this type on tests. Students quickly learn that test items reveal what a teacher really believes is important. It is, therefore, imperative for tests to include some items that challenge students' ability to reason formally. This line of reasoning, however, leads to a fundamental problem.

Unfortunately, since some students initially reason at the concrete level, such a test will include items that these students will almost certainly miss. The wrong thing to do, however, would be to eliminate this type of item completely. A line of attack more conducive to self-regulation and intellectual growth would be to (1) include a few formal items, (2) discuss the answers to these after the test, (3) discuss similar items during class time, (4) use some as thought-provoking homework assignments, and (5) award grades at least partially on the basis of improvement during the semester.

How can tests be designed to fit within the exploration-concept introduction-application learning cycle? In this workshop we have argued that instruction should be designed according to this sequence if it is to encourage self-regulation. That is, a period of exploration precedes concept introduction. Students are then given opportunities to apply the new concept to a variety of situations. Tests fit nicely into this learning cycle as part of the application phase if test items require reasoning patterns and concepts to be applied to new situations.

Suppose for example, that laboratory and classroom activities invite the use of reasoning patterns required to understand controlled experimentation. The subsequent test should include a number of items that evaluate the extent to which students have become able to reason in this way. Not only should test items be included that refer to the materials used in the laboratory activities, but items involving new and unfamiliar materials should also be included. These allow an evaluation of the extent to which the developing reasoning patterns can be generalized to new situations. It is our belief that formal reasoning patterns will become generally useful only after students have gradually reasoned through a wide variety of specific situations that invite the use of formal thought. Test items, if used properly, can aid in this process.

In summary, test items should not only evaluate specific knowledge, they should evaluate concrete and formal conceptual understanding, and they should evaluate the extent to which concrete and formal reasoning patterns have been developed and are generalized. In this way tests will serve both as a means of evaluation and also as valuable learning experiences that can significantly aid the self-regulation process.

4. Concept Application

To provide you with additional experience, join with your partner to classify the following test items into concrete or formal types. Use the clues we have provided together with any criteria you have developed. Please write your answers and reasons in the space provided. (We suggest that you not spend time solving difficult problems now.)

Item 5

When an unknown gas is bubbled through clear lime water, $Ca(OH)_2$, a white precipitate forms. The gas can be assumed to be carbon dioxide providing:

A. all the following are true.
B. no other gas forms a white precipitate in lime water.
C. that the gas does not react chemically with the lime water.
D. no other substance gives a white precipitate with CO_2.
E. there is no marked change in the temperature of the lime water.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 6

Explain each of the following chemical reactions, including whether they are exothermic or endothermic and whether neutralization, ionization, and decomposition are involved.

A. $C + O_2 \rightarrow CO_2 + 84{,}400$ cal
B. $KNO_3 + 8{,}500$ cal $\rightarrow K + NO_3$
C. $NaOH + HCl \rightarrow NaCl + H_2O + 13{,}700$ cal
D. $2H_2O + 116{,}800$ cal $\rightarrow 2H_2 + O_2$

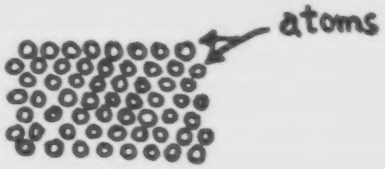
(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 7

The most probable physical state of the substance diagramed at the right is:

A. liquid.
B. solid.
C. can not be determined from information available.
D. gas



Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 8

3.0 moles of $H_2(g)$, and 4.5 moles of $CO_2(g)$ are placed in an empty reaction vessel and the temperature is maintained at 100°C as the reaction is allowed to come to equilibrium. After equilibrium has been established, an analysis of the equilibrium mixture indicats the 2.0 moles of $CO(g)$ and 2.0 moles of $H_2O(g)$ are present. How much hydrogen, $H_2(g)$, is present at equilibrium?

A. 1.0 mole; B. 1.5 moles; C. 2.0 moles; D. 2.5 moles; E. 3.0 moles.

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

Item 9

Which of the following formulas is an acid anhydride?

A. HCl; B. SO_2; C. CaO; D. Na_2O

Please explain your choice.

(Circle one) Concrete Formal

Your reasons (please refer to C1 through F5).

After discussing your classification of the above test items, write one original test item that requires concrete reasoning and one test item that requires formal reasoning. Join a discussion of these items, related issues raised in this module, and the discussion questions on the next page with other workshop participants and a workshop staff member.

Review Questions

1. Are open book tests a means of moving away from testing for recall of information and towards the evaluation of conceptual understanding and reasoning?

2. Do you think the ideas of mastery learning and retaking tests would be helpful in encouraging self-regulation?

3. Do you believe it would be reasonable to expect a student who initially reasons only at the concrete level to master formal subject matter? If not, how might you deal with such a situation ?

4. How do you think your students would initially react to a shift away from recall type examinations to those that require conceptual understanding and formal reasoning? Why might this initial reaction be unfavorable? Be favorable?

5. Suppose you included item 8 on a test. What techniques or ideas (or even materials) would you include in a discussion or activity about this item following the test?

   Homework: Whether you use commercial test items or items prepared by yourself, the next time you give a test, identify the level of reasoning required to solve each problem. Think about student success or failure on these items in terms of reasoning.

PART III
WHAT CAN YOU DO?

9. Teaching Strategies and Goals

10. Suggested Reading

Workshop Planning and Management Tips*

---

* The Tips are intended to help you and/or other science educators present workshops that make use of these study guides. Please consult the Tips regarding the availability of the study materials and other planning needs.

MODULE 9
TEACHING STRATEGIES AND GOALS

Introduction

You may be wondering how you can begin to use the ideas of reasoning patterns and self-regulation immediately, without writing your own textbook or developing all new laboratory activities. In this module, therefore, we shall describe procedures that will help you in stimulating your students to use their existing reasoning patterns and to develop new ones by self-regulation. Your own personal actions and approaches to the students are as important as the teaching materials. We shall also ask you to consider how you might balance course goals directed toward science content with other goals directed toward advancing your students' reasoning patterns.

We believe that the teaching approaches suggested in this workshop are compatible with several theories of teaching and learning. They can best be used as part of an instructional program that also stresses creativity, development of self-worth, self-reliance, and respect for the opinions of others.

Since this module presents the last formal workshop activities, we invite you to consider, during the discussion, these and any related matters about which you have concerns or questions.

Objectives

To assist you in selecting and utilizing teaching strategies that will encourage self-regulation on the part of your students.

To assist you in balancing course goals aimed at content with those aimed at improved reasoning.

Procedure

Before you begin the essays on teaching strategies and goals, find a partner with whom you can discuss some of the points raised in the readings. After you have finished the reading, join a discussion group to compare your ideas concerning teaching strategies and course goals with those of other participants and workshop staff. For your reference, we have included after the review questions a brief summary of the major ideas presented in the workshop.

Instructional Materials

1. Essay: Teaching Strategies for Self-Regulation

Here are some procedures we have found useful for encouraging self-regulation with our students. You'll find that some can be used with very little preparation, while others require substantial planning. Work together with teachers in your school and community to try these approaches so you can share the work, discuss student reactions, and learn from one another's experiences. You may find it valuable to video tape or audiotape your teaching so you may examine your own and your students' behavior more carefully.

Introducing a New Topic

A. Use EXPLORATION activities at the beginning of a new topic or before introducing a new concept. At this time give your students opportunities to investigate in an environment that allows them to ask their own questions and follow their own interests.

B. Use concrete concepts defined operationally through demonstration, examples, and actions to introduce a new topic. At a later time, present more formal definitions of the same concepts and other ones. Forces, for instance, might be illustrated with springs, magnets, and friction before they are related to mass and acceleration.

C. Begin class discussions with simple demonstrations and challenge your students to raise questions or predict the outcome of experiments. Then use the actual results to start an examination of unexpressed assumptions or expectations.

Following Through

D. Allow your students time and opportunities for abundant and repeated experiences. The amount of material covered in your course, at least during the early weeks, may have to decrease. Some teachers report that the pace quickens later because most students have a much better foundation in the subject.

Alternative ways of perceiving relationships help students to resolve contradictions and become aware of their own reasoning. You might then ask them to justify their conclusions, predictions, and inferences regardless of whether these are correct or incorrect.

Questions you might ask of a group or an individual are:

Why are you sure of that?
What is the evidence?
How could you explain that to me?
What other ways of thinking about that problem are there?

E. Encourage your students to interact with one another during discussions and problem-solving sessions. By learning about the viewpoints of others, they'll become more aware of their own reasoning.

Students using formal reasoning patterns will serve as role models for those using primarily concrete patterns. The latter, because of their more limited understanding, will challenge their advanced classmates' short-cuts in reasoning, thus making them rethink their ideas.

Another value of these interactions stems from the fact that such students are more likely to reveal weaknesses and uncertainties by asking apparently stupid questions of one another when the teacher cannot hear. Conceptual difficulties that might never have been revealed can then be dealt with by peers.

F. Allow your students freedom so they may become aware and critical of their own reasoning. Recognize that many of them are accustomed to teaching that delivers information without challenging reasoning patterns. Exploration activities or open-ended questions are, at first, likely to be uncomfortable for some of your students because they must take responsibility rather than having their teacher decide what is right or wrong.

Here are examples of this approach:

> Suppose there is a large rock with a mass of 200 kg in the way of a horse trail you want to build. How might you get it out of the way?
>
> Suppose a farmer finds that carrots in one small part of his field grow much better than they do elsewhere. What might he do so he could ultimately get this larger yield from his entire carrot field?
>
> Jim and Maureen, two physics students, each drop a rock to see which one hits the ground first. Maureen's white rock strikes just a little before Jim's brown rock. How could this observation be explained?

G. Model the reasoning behavior you hope to foster. Reason out loud when you present an explanation or answer a student's question. Let students know that you consider alternative possibilities and are at times unsure of how to proceed. Propose hypotheses, make inferences, compare them with other data, and examine evidence.

Invite the class to join you in this activity by commenting on your ideas, proposing others, and evaluating suggestions. Leave some questions unanswered--they may be too difficult or the answer may be completely unknown.

H. Be receptive to ideas or hypotheses that are apparently off-the-track. Don't squelch a timid first attempt, but encourage it to draw attention to its good points and possibly unusual point of view. Suggest a lab activity, further reading, or discussion to help students re-examine an inadequate reasoning pattern or preconception. Call attention to the reasoning behind a right or wrong answer rather than merely mentioning the answer itself.

I. Avoid the following behaviors, which tend to make your students' thinking remain at a superficial level:

> allowing so little time for responses to a question that few students have time to think about their answers;
>
> evaluating the first answer and then taking control of the discussion without waiting for comments from other students;
>
> suggesting all or part of an answer to your own questions rather than inviting students to propose even partial solutions;
>
> requiring your students primarily to recall pieces of information as opposed to relating or evaluating information.

Using the Laboratory

J. Use the learning cycle to organize lab activities. Always begin with twenty to thirty minutes (or more) of EXPLORATION allowing the students to use their equipment with only a very general goal. Be patient, even if at first they make discoveries that do not fit your plans for the outcome of the session.

After EXPLORATION, be clear and explicit when introducing the new idea or relationship that is at the focus of the day's lab. Encourage your students to help you formulate the new concepts by drawing on their experiences during EXPLORATION.

K. In preparation for a lab activity, invite your students first to identify the variables that might affect the phenomenon to be studied. Then give them a written list of their own suggestions and encourage them to design experiments for testing these. By referring to their own list of variables, your students may learn to control variables more effectively.

L. Raise questions with your students that lead them to reflect on their activities and interpretations. Examples are:

> What were your steps in setting up this experiment?
>
> How would you proceed if you wanted to get better data when repeating the experiment?

What parts of your report would you like to revise?

What conditions in your experiment contributed most to the uncertainity of your measurements?

Making Assignments

M. Before making an assignment from your text, read the selection carefully as we have suggested in Module 4. Identify the demands for formal reasoning it presents; perhaps supplement it with short explanations that will help students using concrete reasoning patterns. Note the clarity of the illustrations and whether they help communicate the message of the text.

N. Assign specially constructed problems that encourage students to evaluate their own reasoning by allowing several answers, each justifiable on a different basis. An example might be this:

> Two cities are located along a river. Johnstown is five miles up the river from Lafayette. During a strike in Johnstown, thousands of gallons of raw sewage were released into the river. This alarmed the officials of Lafayette as the river was used for swimming. To prevent infection, they dumped large quantities of strong anticeptic into the river.
>
> For some weeks after the antiseptic had washed away, the river was brown and murky and filled with small pieces of plant materials. City officials in Lafayette blamed those in Johnstown for the state of the river. Officials in Johnstown blamed those in Lafayette for dumping antiseptic into the river. Who do you think is to blame? Please explain your conclusion.

Testing

O. When you select items for a test, make sure that their demands on science knowledge and on reasoning are appropriate. Avoid problems in which ingenious reasoning overshadows the science--use these only in supplementary materials for gifted students.

P. Include test items on which you ask students to justify their answers so you can assess their reasoning patterns as well as their knowledge. Module 8 has more detailed suggestions on this topic.

2. Essay: Course Goals--Content or Reasoning?

Teachers who intend to cover new material must expect to allow for self-regulation if they wish their students to come to a good working understanding of new ideas. In view of this consideration, we should like to rephrase the question in the title to "Course Goals--Content With or Without Reasoning?"

How much time will be needed depends on the level of the course and preparation of the students. Less time will be needed in an advanced placement course where most students reason formally and have a background of experience and understanding in science. More time will be needed in the junior high school where students are less experienced and may reason predominatly with concrete patterns. Nevertheless, all students seem to benefit from concrete experiences offered before concepts and relationships are introduced.

Usually schools define course goals exclusively according to the major topics covered, allowing the individual teacher to choose emphasis and elaboration of details. Now you may wish to consider including goals related to your students' reasoning.

Are the reasoning goals compatible with all content goals?

Are the topics in your course sequenced in order of increasing use of formal reasoning patterns?

Is there sufficient opportunity for concrete experience in the laboratory?

Are students encouraged to relate mathematical symbols closely to experimental data?

Are there provisions for making students aware of their own reasoning?

Review Questions

Please join a group of participants and workshop staff to discuss some of the following questions. On the next page we have a summary of the major ideas presented in this workshop for your quick reference.

1. Have you any indication of concrete reasoning patterns used by students in your courses? Describe some of your observations.

2. Do you feel a need to include the development of reasoning as an important course goal? Would you subordinate some other goals to that one? If so, what kinds of changes will you make? How could you tell your students about this goal?

3. What possibilities are there within your present courses for helping your students develop formal reasoning?

4. What contributions can the traditional lectures make to self-regulation and the development of formal reasoning?

5. What contributions can the laboratory in your course make to self-regulation and the development of formal reasoning?

6. What contributions can class discussion in your course make to self-regulation and the development of formal reasoning?

7. How might new course formats, such as individualized instruction, be made appropriate for stimulating self-regulation and developing formal reasoning?

Summary of Major Ideas

1. Piaget's theory describes two major levels of logical reasoning in human intellectual development: concrete thought and formal thought. Earlier levels appropriate to the behavior of young children may be called prelogical.

2. Each of these two levels is characterized by certain reasoning patterns that may be used by the individual to classify observations, interpret data, draw conclusions, and make predictions. Some specific comparisons between the two levels follow:

	CONCRETE THOUGHT	FORMAL THOUGHT
(a)	Needs reference to familiar actions, objects, and observable properties	Can reason with concrete and formal concepts, relationships, intangible properties, and theories
(b)	Uses classification, conservation, serial ordering, and one-to-one correspondence in relation to items above	Applies combinatorial, classification, conservation, serial ordering, and proportional reasoning in relation to intangible items (a) above
(c)	Needs step-by-step instructions in a lengthy procedure	Can plan a lengthy procedure given certain overall goals and resources
(d)	Is not aware of his or her own reasoning, inconsistencies among various statements, or contradictions with other known facts	Is aware and critical of his or her own reasoning, actively checks the validity of conclusions by appealing to othe/ known information

3. Most persons older than twelve years use formal reasoning patterns under some conditions and concrete reasoning patterns under others. The latter is likely to occur whenever the subject matter is unfamiliar, as is the case for a student beginning work in a new area. The former is likely to be the case for an experienced worker in a scientific field.

4. The process of self-regulation plays a vital role when an individual advances from the use of a concrete reasoning pattern to the use of a formal reasoning pattern. Self-regulation begins with one's awareness that the concrete reasoning pattern is inadequate. It proceeds through direct experience with the phenomena and the introduction of related organizing principles and major concepts.

5. A person who uses only concrete reasoning patterns is likely to proceed through self-regulation in a new subject much more slowly than a person who reasons formally in connection with other studies. The latter individual benefits from the possibility of transferring formal reasoning patterns to the new area, especially if the new and old are closely related as is the case with mathematics and science.

6. Some students who are required to learn formal-level material in a subject in which they so far have only used concrete reasoning may go through self-regulation spontaneously. Other students, with less experience or self-awareness, are not likely to experience the necessary self-regulation; instead, they will memorize certain prominent words, phrases, formulas, and procedures, but will apply these with little understanding unless the teaching program takes their specific needs into account.

7. Tests should be designed to evaluate the students' reasoning and also help them engage in self-regulation by reflecting on their own thinking.

Organizing a Workshop

After you have tried out some of these ideas in your own teaching, you may wish to present these workshop materials to a group of science teachers in your area. We suggest that you follow our example and gather a small working committee that will plan and staff the workshop. Since the workshop materials are now available for your use, your committee's major responsibilities will be related to recruiting participants, arranging for space and equipment, and then presenting the activities.

As a first step, we suggest that you acquaint yourself with the Workshop Planning and Management Tips included at the end of this book. Or, raise the matter with the leader of your workshop.

MODULE 10
SUGGESTED READING

Introduction

In this module we are presenting articles on the subject of stages of intellectual development and self-regulation to supplement the brief presentations that were included in the previous modules. For those of you who wish to do further reading, we have also provided a list of articles and books about these related topics.

Objectives

To provide you with additional examples and further reading about the ideas that you were introduced to in the workshop, and to make available a bibliography that you can use for further study.

Procedure

For further background on Piaget's theory as related to science teaching, read one or more of the reprints included in the Instructional Materials. For additional information on Piaget's theory in general (not specially related to science teaching), consult one or more of the books or articles listed in the bibliography--most of the books are available as paperbacks.

Instructional Materials

This module contains the following materials:

1. Reading list of suggested books and articles.
2. Anton E. Lawson and John W. Renner, "Piagetian Theory and Biology Teaching," American Biology Teacher, 37(6), 336-343, 1975.
3. Anton E Lawson, "Developing Formal Thought Through Biology Teaching," American Biology Teacher, 37(7), 411-429, 1975.
4. John W. Renner and Anton E. Lawson, "Promoting Intellectual Development Through Science Teaching," The Physics Teacher, 11(5), 273-276, 1973.
5. J. Dudley Herron, "Piaget for Chemists," Journal of Chemical Education, 52(3), 146-150, 1975. (In this article Professor Herron has focused his attention on teaching chemistry to college freshman. His remarks are extremely important for teachers of college students and even more important for teachers of secondary school students.)
6. Jean Piaget, "Cognitive Development in Children: Development and Learning," Journal of Research in Science Teaching, 2, 176-186, 1964.

Suggested Reading

Books

1. Irene J. Athey and Duane O. Rubadeau, (Eds.) *Educational Implications of Piaget's Theory*, Xerox College Publishing, Waltham, Mass., 1970.

2. David Elkind, *Children and Adolescence, Interpretative Essays on Jean Piaget*, Oxford University Press, New York, 1970.

3. Richard I. Evans, Jean Piaget: *The Man and His Ideas*, E. P. Dutton, Co., New York, 1973.

4. John H. Flavell, *The Developmental Psychology of Jean Piaget*, Van Nostrand, New York, 1973.

5. Hans G. Furth, *Piaget for Teachers*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1970.

6. Hans G. Furth and Harry Wachs, *Thinking Goes to School: Piaget's Theory in Practice*, Oxford University Press, New York, 1974.

7. Herbert Ginsburg and Sylvia Opper, *Piaget's Theory of Intellectual Development*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969.

8. Richard M. Gorman, *Discovering Piaget*, Charles E. Merrill Pub. Co., Columbus, Ohio, 1972.

9. J. McV. Hunt, *Intelligence and Experience*, Ronald Press Co., New York, 1961.

10. Barbel Inhelder and Jean Piaget, *The Growth of Logical Thinking from Childhood to Adolescence*, Basic Books, New York, 1958.

11. Chester A. Lawson, *Brain Mechanisms and Human Learning*, Houghton Mifflin Co., Boston, 1967.

12. John L. Phillips, Jr., *The Origins of Intellect: Piaget's Theory*, W. H. Freeman and Co., San Francisco, 1969.

13. Jean Piaget, *Genetic Epistemology*, W. W. Norton and Co., New York, 1970.

14. Jean Piaget, *The Psychology of Intelligence*, Littlefield, Adams, and Co., Paterson, New Jersey, 1968.

15. Jean Piaget, *The Science of Education and the Psychology of the Child*, The Viking Press, Inc., New York, 1971.

16. Jean Piaget, *To Understand Is to Invent*, Grossman Publishers, New York, 1973.

17. John W. Renner, et al. Research, Learning and Teaching with the Piagetian Model, University of Oklahoma Press, Norman, 1975.

18. John W. Renner and Don G. Stafford, Teaching Science in the Secondary School, Harper and Row, New York, 1972.

19. Milton Schwebel and Jane Raph (Eds.), Piaget in the Classroom, Basic Books, Inc., New York, 1973.

Articles

1. Entire issue, Journal of Research in Science Teaching, Vol. 2, 1964. (Articles by Piaget, Karplus, Ausubel, and Duckworth.)

2. Richard K. Boohar, "Investigative Laboratories for High Enrollments and Low Budgets," Journal of College Science Teaching, 4(4), 261-263, 1975.

3. J. S. Bruner and Helen J. Kenney, "Representation and Mathematics Learning," In Cognitive Development in Children, Ed. by Kessen and Kuhlman, University of Chicago Press, 1970.

4. David Elkind, "Piaget and Science Education," Science and Children, Nov., 1972.

5. Norris Grant and John W. Renner, "Identifying Types of Thought in 10th-Grade Biology Students," American Biology Teacher, 37(5), 283-286, 1975.

6. Elizabeth F. Karplus and Robert Karplus, "Intellectual Development Beyond Elementary School I: Deductive Logic," School Science and Mathematics, 70(5), 398-406, 1970.

7. Robert Karplus and Rita Peterson, "Intellectual Development Beyond Elementary School II: Ratio, A Survey," School Science and Mathematics, 70(9), 813-820, 1970.

8. Lawrence Kohlberg and Rochelle Mayer, "Development as the Aim of Education," Harvard Educational Review, 42(4), 449-496, 1972.

9. Anton E. Lawson, Anthony J. D. Blake, and Floyd H. Nordland, "Training Effects and Generalization of the Ability to Control Variables in High School Biology Students," Science Education, 59(3), 387-396, 1975.

10. Anton E. Lawson and John W. Renner, "Relationship of Science Subject Matter and Developmental Levels of Learning," Journal of Research in Science Teaching, 12(4), 347-358, 1975.

11. Anton E. Lawson and Warren T. Wollman, "Encouraging the Transition from Concrete to Formal Cognitive Functioning: An Experiment," Journal of Research in Science Teaching, (in press).

12. Edward G. Palmer, "Accelerating the Child's Cognitive Attainments Through the Inducement of Cognitive Conflict: An Interpretation of the Piagetian Position," Journal of Research in Science Teaching, 3, 318-325, 1965.

13. Jean Piaget, "Intellectual Evolution from Adolescence to Adulthood," Human Development, 15, 1-12, 1972.

14. John W. Renner and Anton E. Lawson, "Piagetian Theory and Instruction in Physics," The Physics Teacher, 11(3), 165-169, 1973.

15. Sidney Strauss, "Learning Theories of Gagne and Piaget: Implications for Curriculum Development," Teacher's College Record, 74(1), 81-102, 1972.

MODULE 10 REMOVED DUE TO COPYRIGHT RESTRICTIONS

WORKSHOP PLANNING AND MANAGEMENT

Introduction

At some time in the future you may consider presenting a workshop on Science Teaching and the Development of Reasoning to a group of fellow science teachers in your community. We certainly hope you will help spread the ideas through personal involvement. Just reading about patterns of reasoning and self-regulation in a psychology book are very inadequate when compared to working on puzzles, seeing films, engaging in laboratory activities, and comparing ideas with professional colleagues.

Objective

To help you plan and present a workshop on Science Teaching and the Development of Reasoning.

Procedure

In the attached Instructional Materials, we have included the following items:

Organizing Tips -- how to get started.
Preparing the Orientation Module -- including a sample.
Workshop Staff Responsibilities -- how to share the effort.
Presenting the Workshop -- how to help the participants get most out of the experience.

In these materials, we have provided details that may be unnecessary for you or do not apply to your situation. To get the most benefits from these Tips without wasting time, scan the pages quickly for the main points we call to your attention. Then follow up on items you find worthwhile, but skip materials for which you do not need our suggestions.

Ultimately, we would like to know how your plans worked out. Please let us know, at the address on page P-4, about your experience, any changes you made, and what you would suggest to other users.

ORGANIZING TIPS

We suggest that you begin by selecting a small working committee that can help you plan and staff the workshop. Three or four persons altogether, somewhat familiar with the theory of Piaget, will be able to do all the necessary preparation. As your planning proceeds, you should meet with your colleagues to discuss workshop procedures and responsibilities. The following matters will require attention:

(1) Identifying the participant group. Suitable groups might be NSTA members who are attending a regional meeting, faculty from one or several schools in your area, or participants in an in-service course. Aim for a total number of at least ten persons to permit group interaction; twenty to thirty is a comfortable size.

(2) Scheduling. Depending on the time available, you can program a more or less complete presentation of the workshop. Here are some options:

(a) Three hours -- introduction to both learning cycles concerning reasoning patterns and self-regulation (Modules 1, 2, 3, and 5);

(b) Five hours -- focussed treatment of both learning cycles -- (Modules 1, 2, 3, 5, 6, and 9);

(c) Eight hours -- hurried treatment of both learning cycles concerning reasoning patterns and self-regulation -- (Modules 1-9);

(d) Twelve hours -- thorough treatment of both learning cycles in complete workshop (Modules 1-9);

(e) More than twelve hours -- complete workshop presentation augmented by analysis and/or preparation of additional teaching materials.

Select a plan for presenting the workshop by using the above suggestions as a guide. Fix the date(s) and hours when the presentation will take place, keeping in mind the availability of the participants. Morning and afternoon sessions on the same day, half-day sessions on successive days or during successive weeks, five or six two-hour evening sessions on a weekly basis, are all suitable possibilities. Allow about an hour for a full discussion on each module.

If a day or more elapses between workshop sessions, some of the reading can be assigned as "homework." The sessions themselves can then be used more for discussion, films, and laboratory activities. Under these conditions, the total classroom time may be less than suggested above.

If the workshop sessions extend over a period of several weeks, the participants could use puzzles or specially designed "concrete" and "formal" test questions with their students. They might report their findings to the workshop group for comparison and discussion.

(3) Publicity. Allow sufficient time in advance of the workshop date to contact the prospective participants. An attractive poster or one-page letter can include the necessary information about place, time, date, any fee to defray costs, registration deadline, and workshop leadership, together with a persuasive invitation -- see page P-5.

Request registrants to indicate their preferred science area (one of five offered in the materials) so you can prepare the correct number of study guides and laboratory materials.

(4) Special workshop materials. The special workshop materials are available from:

Reasoning Workshop
Lawrence Hall of Science
University of California
Berkeley, California 94720

or may be partly constructed by you and your colleagues. They include:

(a) Workshop Study Guides in five editions (general science, earth science, biology, chemistry, physics); obtain the necessary number for workshop staff and participants.

(b) Twenty chains of ten #1 gem paper clips for Module 1; obtain locally.

(c) "Formal Reasoning Patterns" film for Module 3 may be rented or purchased from LHS. (The film "Formal Thought" [Davidson, 1971] may be used instead if it is more conveniently available.)

(d) 16mm sound film projector and screen; obtain locally.

(e) Mirror puzzles for Module 5, one puzzle for four participants; purchase from LHS or produce locally.

(f) Laboratory materials for Module 6, one set for four participants; purchase from LHS or obtain locally -- see next page.

General Science and Physics

- 2 C-clamps
- 6 assorted steel strips, approx. 2cm x 0.5mm x 30cm
- 8 small ferrite magnets
- 4 helical springs
- 1 ruler

Earth Science and Chemistry

- 4 test tubes
- 2 30cm length glass tubing, 4mm
- 2 1-hole rubber stoppers
- 1 pint vinegar*
- steel wool
- water with food coloring*
- ruler

Biology

- 4 popsicle sticks
- 4 pieces sponge
- 2 medicine droppers
- 2 plastic baggies
- matches*
- 2 earthworms*
- salt water*
- fresh water*
- sugar water*

*Provide locally, whether or not you purchase other materials from LHS.

If you plan to present workshops frequently and/or coordinate numerous workshops in your region, please contact us for special arrangements to establish a local dissemination center at your institution.

Ordering information and prices may be obtained from the above address or from order forms distributed by your workshop leader.

(5) Space. We suggest that you allow about thirty square feet per participant, in at least two different but nearby rooms.

(6) Staff. Plan to have about one staff member for every six to eight participants. If necessary, augment the planning committee with additional staff members for the workshop presentation.

(7) Orientation Module. Use the suggestions given in the next section of these Tips to prepare an Orientation Module for the participants.

(8) Staff responsibilities. The workshop staff plays an exceedingly important role during the workshop to help participants use the instructional materials and form discussion groups. Allow time during the week immediately preceding the workshop for staff orientation as suggested in the "Workshop Staff Responsibilities" section of the Tips.

(9) Room arrangement. The placement of furniture and signs to help direct the participants is described in the "Presenting the Workshop" section of these Tips.

(10) Workshop fee. Presentation of the workshop entails certain costs for printed study guides, film rental or purchase, projector rental, special supplies you purchase from the Lawrence Hall of Science or prepare at your institution, the academic credit, and staff time. Determine a reasonable fee that enables you to recover your expenses. Note that only the study guides are "consumed" by the workshop. The mirror puzzles and other laboratory materials can be re-used in future workshops.

WORKSHOP ON SCIENCE TEACHING AND THE DEVELOPMENT OF REASONING

This self-paced interactive workshop for secondary school science teachers is based on the theory of Jean Piaget. By participating in the (*number*) sessions, you will be able to find out how your science teaching can be used to help your students improve their reasoning and conceptual understandings. You will also find out how you can interpret some of the reasoning patterns used by your students.

The workshop combines group and individual activities that make use of films, puzzles, laboratory materials, discussions, and readings. You will examine science texts and test questions that are widely used in secondary science courses. Five editions of the study guides are available so you may select the one that best fits your present teaching responsibilities in general science, earth science, biology, chemistry, or physics.

The workshop uses materials that were tested at the 1976 and 1977 NSTA National Conventions. It was developed by a nationwide team of science educators sponsored by the Lawrence Hall of Science, University of California, Berkeley.

The steering committee for the workshop consists of (*include names and brief addresses of committee members*).

Date(s) and time(s):
Place:
Workshop Fee:

Registration is limited to (*number*). Please register before (*date*) by sending in the registration form below.

- -

Workshop Registration   Clip and mail to (*name, address*)

I wish to register for the Workshop on Science Teaching and the Development
of Reasoning without academic credit ____ (Fee $)
with academic credit ____ (Fee $)

Name ______________________________

Address ______________________________

____

____

Science area (please make first and second choices)

General Science ______
Earth Science ______
Biology ______
Chemistry ______
Physics ______

Deadline for receipt of registration is (*date*).
Please enclose the workshop fee made payable to (*payee*).
If your registration cannot be accepted, your check will be returned.

PREPARING THE ORIENTATION MODULE

Once your plans are completed, you are in a position to prepare the Orientation Module that will inform the participants about their procedures in the workshop. In this connection you should keep in mind that few of them will be familiar with self-paced learning. Working individually may be a source of anxiety that can be eased by giving a clear description of the ground rules in advance and later having the staff be friendly and reassuring as well as contributing to the workshop objectives.

Look at sample orientation module on the next pages. You may use a similar form, but provide the factual information (meeting rooms and times, staff members) that applies to your workshop. We also suggest diagrams of the rooms you use, with an indication where the projector and lab materials will be placed.

Here is an estimated minimal time table for a workshop using two rooms:

Session I	Room A	Room B
Orientation (two sessions)	8:45-9:15	
Module 1 25-40 minutes	9:00-10:00	
Module 2 25-40 minutes		9:30-10:30
Module 3 35 minute film (show at 10:00 and 10:40)	10:00-11:20	
Module 4 25-40 minutes[+]		10:30-11:45
Discussion 20-45 minutes	11:15-12:00	11:45-12:15
Module 5 25-40 minutes[+]	11:45-12:15	
Session II		
Module 5 25-40 minutes[+]	1:30-2:15	
Module 6 25-40 minutes[+]		1:30-2:45
Module 7 25-40 minutes[+]	2:15-3:15	
Module 8 25-40 minutes[+]		2:45-4:00
Module 9 25-40 minutes	3:15-5:00	4:00-5:00

[+] Arranged for five separate content groups.

Make a time table analogous to the above for your own workshop to help you decide how to locate and schedule the modules, films, and so on. We suggest, however, that you not communicate it to the participants to avoid undermining the self-paced approach.

Duplicate the required number of Orientation Modules for the participants and staff, with a few extras in case of unforeseen events.

Distribute the printed materials after the orientation speach. If you have enough lead-time, you might mail out the Orientation Module and study guides to the participants, so they can prepare themselves in advance. IF YOU MAIL THEM, MAKE SURE THAT THEY ARE BROUGHT TO THE WORKSHOP. Provide some duplicate copies to replace lost ones.

ORIENTATION MODULE

Introduction

This Orientation Module describes the overall program, use of audio-visual materials, scheduling, and related matters for the self-paced workshop you are beginning. The workshop materials have been developed under the sponsorship of the Lawrence Hall of Science, University of California, with partial support from the National Science Foundation.

Activity and interaction are key ingredients of this workshop. We have planned a minimum of formal presentations and are encouraging you to involve yourself in all activities in the manner and to the depth you wish. Though there is a great deal of reading material in the modules, we urge you not to spend all your time on that, but to exchange ideas frequently with your partner, other members of a discussion group, and the workshop staff.

Many of the ideas we present in these modules can be improved upon. Apply your experience as a science teacher to help the other workshop participants, the staff, and yourself develop our suggestions into genuinely useful teaching tools.

Objective

To assist you in participating profitably in the workshop activities.

Procedure

Please read the attached instructional materials carefully. Then look around the room for a posted diagram of the layout and the direction signs indicating the locations of activities. If you have questions, consult a workshop staff member. They are:

Workshop leader:

Workshop staff:

Instructional Materials

1. Workshop Modules

We shall begin by listing the titles of all modules and indicating the nature of the activities. Select the study guides for your science area.

MODULE	MEDIA	PARTICIPANT INTERACTION
Orientation	Live Speaker	Group
Part I. Reasoning Patterns		
1. How Students Think	Paper Clips	Individual/group
2. Concrete and Formal Reasoning Patterns		Individual/group
3. "Formal Reasoning Patterns"	Film	Group
4. Science Texts and Reasoning Patterns[+]		Individual/partner
Discussion		Group
Part II. Teaching for Self-Regulation		
5. Self-Regulation and the Learning Cycle[+]	Mirror Puzzle	Individual/group
6. The Laboratory and Self-Regulation[+]	Lab Activity	Individual/partner
7. Concrete and Formal Concepts[+]		Individual/partner
8. Tests and Self-Regulation[+]		Individual/partner
Part III. What Can You Do?		
9. Teaching Strategies and Goals		Individual/group/partner
10. Suggested Reading		Individual (post-workshop)
Workshop Planning Management		Individual/group

[+] Available for General Science, Earth Science, Biology, Chemistry, and Physics. Work with a group from your own subject matter area.

2. Workshop Schedule

Plan to spend (*thirty to forty-five*) minutes on each module.

As you can see from the module listing above, much of the workshop involves collaboration with a partner or group. We believe you would benefit from joining with other participants from your own content area. As you complete the early modules, please look for suitable partners to join them no later than Module 4. Workshop staff members will help you find partners.

The film for Module 3 will be shown at two times, between about (*time*) and (*time*). It lasts for thirty-five minutes. If the film begins while you are working on Module 2, interrupt this to see the film. We will announce the film showing in the Module 2 area.

We have divided the workshop into two sessions, as follows:

Session I	*8:45 A.M. - 12:15 P.M.*	*Orientation and Modules 1, 2, 3, 4 and 5.*
Lunch	*12:30 P.M. - 1:30 P.M.*	
Session II	*1:30 P.M. - 5:15 P.M.*	*Modules 5, 6, 7, and 8.*

We do not intend the concluding times to be interpreted rigidly and will have staff members available for additional discussion of any of the modules or related questions after "closing time."

Rooms A and B are side-by-side; Room C is across the hall. Module 1 is located in Room A, and subsequent modules will alternate among the three rooms. The final locations of all modules and activities will be announced with signs in the rooms.

Several of the modules include provisions for group discussions. A workshop staff member will be available to serve as discussion leader. He/she will place a DISCUSSION sign on the table to indicate where participants might gather for the discussion.

4. Evaluation

At the end of the workshop you will receive an evaluation questionnaire on which you can tell us your opinions and reactions concerning the workshop. We hope to learn about your ideas.

WORKSHOP STAFF RESPONSIBILITIES

You and your colleagues on the workshop staff should become quite familiar with the workshop materials. You will have to concentrate on several aspects of operation while the workshop is in progress. These include:

(1) making the participants feel welcome and at ease;
(2) assuring operation of the film projector (a professional operator may take care of this matter);
(3) maintaining an orderly flow of participants from one module to the next;
(4) facilitating the formation of partnerships and study discussion groups as suggested in the individual modules;
(5) answering questions and providing information to supplement the printed materials and relate them to the participants' experience.

During the week preceding the workshop all the staff should re-read the modules along with the specific suggestions in the "Presenting the Workshop" section of these Tips. Then hold a planning conference in which all of you can review the modules one by one, raise and discuss any questions about the content, and take responsibilities for certain duties whose detail depends on the rooms and schedule you have arranged.

In a thirty-person workshop with five staff members, two staff members might be stationed permanently in each room and serve as "experts" regarding the modules in their rooms. The workshop leader could direct the orientation activity and then help out when a module is crowded or more discussion leaders are needed.

The workshop is designed to allow for substantial self-pacing, but the space and time available will set limits if most of the activities are to be used. Breaking the workshop into two or more sessions allows for variable "intermission" periods, which may be longer for the fast-working participants and shorter for their more deliberate colleagues.

Certain parts of the workshop especially benefit from the group environment (mirror puzzle and discussion in Module 5, lab activity in Module 6, final discussion in Module 9), while others can be carried out almost as well singly (reading of text excerpts in Module 4, all of Module 10). Use this distinction to help participants spend their time wisely.

Concluding the workshop can be handled in several ways. It might just fade out, as people leave the final discussion and the group shrinks until very few are left. Or, everyone might be gathered together at a predetermined time for brief concluding remarks by the workshop leader, who encourages everyone to apply the ideas that were presented and "keep in touch" regarding their value. A brief evaluation questionnaire will be useful to you in pointing out strengths and weaknesses of the presentation that will make your next workshop more effective.

PRESENTING THE WORKSHOP

In this section of the Tips we shall comment on special arrangements and staff responsibilities in the modules of the workshop.

Orientation

Orienting the participants with a short welcoming speech of about five minutes will provide a helpful transition for adults not accustomed to self-paced learning in a group setting.

Preparation. Set aside an area near the workshop entrance where ten to twenty participants can gather. Have the Orientation Module and name tags ready for distribution. Staff members should wear their name tags.

Suggestions for the staff. If the total number of participants is larger than can be accomodated in the orientation area, admit them in groups. Welcome the participants, point out the staff members, distribute name tags to everyone unless the group is well acquainted, and very briefly review your reasons for presenting the workshop.

Then explain that the workshop is self-paced and that there will be no group presentation after the orientation. Invite all participants to find partners or to join in slightly larger groups from one content area for discussing their readings and helping one another during the activities.

Encourage them to involve themselves in all the workshop activities and to talk to you and the workshop staff about any problems that arise. Point out that many of the modules include puzzles and questions that they may find hard to answer -- these are placed there not to evaluate the participants' thinking, but to give examples of the type of challenge facing students. Hence, no one should feel inadequate if he or she does not come up with a very elegant response immediately.

Finally, distribute the Orientation Module and invite the participants to read these carefully in the Module 1 area before picking up the study guides and starting on Module 1. After the group leaves, a new group enters the orientation area and the process is repeated until all the participants have been welcomed. Follow the last group to the Module 1 area.

Module 1 How Students Think

Preparation. Since this is the workshop's first module, the physical space should be properly arranged, clearly marked, and easily accessible. The study guides should be available for distribution. The area intended for each puzzle should be identified by a large sign. The paper clip chains must be available in the Ratio Puzzle area.

Suggestions for the staff. Encourage the participants coming from the orientation to form groups of two to four, matched by subject area, for discussing the Orientation Module and then for studying Module 1. When people are ready, give them the workshop materials and urge them to work on one module at a time. Invite them to start with any puzzle they please, and then to investigate the others and compare their ideas frequently.

Be prepared to encounter many participants who cannot believe that students really gave some of the incorrect answers. Point out to them that they will see unrehearsed students in the film of Module 3.

Some participants may be upset because they believe they were tricked into "missing" a puzzle. Tell them that persons do not necessarily apply their reasoning abilities under all circumstances. Explain that a "diagnosis" of reasoning ability is difficult to make reliably and certainly would depend on consistent approaches to many puzzles or tasks requiring reasoning.

Watch for group interaction among the participants. If you see any isolated individuals, approach them to discuss their work and introduce them to other participants for exchanges of ideas unless they express a preference for working by themselves.

Expect to spend about an hour on Module 1. After an hour, most participants--even some who started late--should have completed at least one puzzle and would benefit from proceeding to Module 2.

Module 2 Concrete and Formal Reasoning Patterns

Preparation. The entire area can be furnished with tables and chairs that allow groups of four to ten participants to sit together. To avoid crowding and allow some mobility, provide some extra seats. Post large signs to indicate areas for analysis of student answers and the discussion (see page 2-1, "Procedure").

Suggestions for the staff. The beginning of this module requires individual reading and study, hence the room may be fairly quiet.

Once the participants have finished reading, they will continue with the analysis of the student answers and finally engage in discussion in the area indicated. Join a group to get it started, possibly by raising some questions that you were asked earlier in the workshop, or using the following:

Why didn't the six students give answers that could be classified more consistently?

Should a teacher try to classify his students according to their level of reasoning? How could this be done?

Can anyone cite a good example of a student using concrete reasoning patterns? Formal reasoning patterns?

What appear to be some common features of concrete reasoning patterns? Of formal ones?

Leave the group and help another one get started unless time permits you to follow the discussion extensively.

Pay attention to the time so you can help all participants get to one of the film showings, interrupting Module 2 if necessary. Keep in touch with the staff members for Module 3 to learn of possible changes in the schedule.

Module 3 "Formal Reasoning Patterns"

Preparation. The film projector and film are needed. Depending on your facilities, chairs may have to be rearranged for comfortable viewing of the screen.

Suggestions for the staff. Invite early arrivals to take seats and read about the four filmed tasks in their study guide. Start the projector when you have a substantial group of viewers. You may have to adjust the schedule so all participants have a chance to see the film, at least in part.

Module 4 Science Texts and Reasoning Patterns

Preparation. It might be useful to have copies of the texts used in Module 4 available for reference.

Suggestions for the staff. The participants should form groups with colleagues from the same subject area. Walk among them while they are working to learn their reactions to the excerpts and to answer questions or comment on their ideas.

Discussion

The purpose of this discussion is to allow participants to review and consolidate their thinking about reasoning patterns. Questions, doubts, concerns and uncertainties may be expressed at this time.

Background information. Since developmental theory has been applied to science teaching by only few people and for a short period of time, nobody has the answer to some of the questions that may arise. We hope that the interest and creative ideas of the participants will enable them to contribute to everyone's better understanding of the theory's strong points and limitations. The workshop materials reflect our substantial experience and ideas, even though we do not have "all the answers."

One question that is asked occasionally concerns a test with which the reasoning patterns used by the respondent can be identified. Such tests are being devised and show that few high school and college students would use either concrete or formal reasoning patterns to the complete exclusion of the other. We believe that a science teacher can also appraise a student's use of various reasoning patterns on science tasks (suggestions are included in the later modules) without making up a test that is used separately from a learning experience.

A second question concerns a youngster's potential for formal thought, which is often put near twelve years of age. Participants who have read or heard of this fact may question the value of developmental theory for teaching of older students.

In our experience, the "potential" for formal thought is only partially realized even in many adults. Furthermore, the ease with which a person applies formal reasoning in a new area such a chemistry, even after using formal reasoning in a new area such as chemistry, even after using formal operations in another area (mathematics, reading), varies widely from person to person. We, therefore, believe it is important for a teacher to be aware of the reasoning patterns actually used by students and to chart their progress as new topics are introduced.

Preparation. Arrange the furniture for group discussion, with as many groups as you have staff members available.

Suggestions for the staff. Invite the participants to form about equally sized groups after they have completed Module 4. Urge them to describe their reactions to the idea of reasoning patterns as described in Module 2 and illustrated in Modules 3 and 4. As much as possible, solicit comments from other participants in response or elaboration, rather than serving as "answer man" who replies to each question before turning to the next item.

Module 5 Self-Regulation and the Learning Cycle

This module presents the second key idea of the workshop, and the one which is most productive as concerns teaching innovations.

Preparation. Assemble and set out the mirror puzzles, which will be used by participants at the beginning of this module. Duplicate additional copies of pages 5-3 and 5-4.

Suggestions to the staff. Help to get participants into groups of about two to three to use the mirror puzzle after reading the introductory material of the module. If time allows, join first one group, then another, to encourage their efforts and observe their procedures. These initial explorations might consume about twenty minutes, but urge groups to allow time for reading the essays and discussing their reactions along with some of the review questions.

Help in the formation of the discussion groups at the end of the module and participate either as discussion leader or as discussant. Help all group members to contribute and steer the conversation to take up specific aspects of learning difficulties or suggested teaching approaches.

Module 6 The Laboratory and Self-Regulation

The essential feature of the beginning of this module is to give the participants a personal experience with the exploratory phase of the learning cycle before they try to apply this idea in their teaching. The oscillator, steelwool, or earthworms offer a simple way of getting a great deal of variability. If you prefer, a different laboratory activity, substitute it and prepare a suitable handout for the participants.

Background information. In the usual learning cycle, the EXPLORATION activity beginning this module would be followed by CONCEPT INTRODUCTION (suitable concepts are variable, period, periodic motion) and CONCEPT APPLICATION to functional dependence of the outcome on the other variables. Because you "students" know too much, we suggest that the exploration be followed instead by their discussing possible follow-up activities. NOTE THAT THE LEARNING CYCLE CONTRADICTS a frequent approach in science labs, where the answers are derived formally before most students are aware of the questions being asked.

Preparation. Distribute the laboratory materials on the tables. Provide graph paper at an accessible place where participants can pick it up if they wish.

Suggestions to the staff. Invite each team of three to five participants to use one of the equipment sets for the investigation described on page 6-2. Since we recommend you provide only three options (oscillator, steel wool and earthworms), you might urge earth science and chemistry teachers to use the steel wool activity, general science and physics participants to use oscillators, and biology teachers to use the earthworm activity.

As you walk from station to station, ask about the property being varied, observe whether the other factors are being kept the same, and challenge the investigators to try out additional objects. This is the key to exploration: to continue examining a problem from many different points of view, with frequent new hypotheses.

After ten to twenty minutes of exploration, help participants gather in larger groups to discuss their experience and consider ways in which the exploration might be followed up. This discussion need not be longer than three to five minutes. Rather, encourage the participants to read the essays and then answer the review questions. Join the groups to find out some of their ideas in answer to the questions at the end of the module.

Module 7 Concrete and Formal Concepts

Preparation. Tables and chairs will accommodate the participants.

Suggestions for the staff. Since most of this module involves reading and exchanges of ideas with a partner, walk among the participants to share some of their thoughts, answer questions, and find out about their reactions to the questions on pages 7-2 and 7-5. Invite comments about the essay in item 2 and the summary lists of reasoning patterns on page 7-4.

Module 8 Tests and Self-Regulation

Preparation. The room arrangement of tables and chairs used for Module 2 will serve here as well. Staff members should work through all the items in advance so they can assist participants if necessary.

Suggestions for the staff. Make sure that all participants have a partner with whom they can exchange ideas during and after their reading. Be prepared to compare different question-answering approaches with regard to their use of concrete and formal reasoning patterns.

Module 9 .Teaching Strategies and Goals

Preparation. All participants will be involved in the final discussion, so all of the workshop space can be used and all staff members will be available. Tables and chairs are the only required furnishings. Since this is the last module, you may wish to provide for a final evaluation.

Items that might be included in the evaluation are:

Which modules were particularly interesting or instructive?

Comment on thyphysical facilities.

Did you find the workshop staff cordial, helpful, and informed?

Were the exchanges with your partner(s) and group colleagues valuable?

Comment on the workshop's value in terms of the time and effot you invested.

Which ideas appeared most relevant to your teaching?

Do you have any ideas at present for applying the suggestions presented in the workshop?

Suggestions for the staff. The early part of this module involves the participants in reading and exchanges with their partners, while the later part consists of a discussion. Help the transition between these two activities and join one of the discussion groups. Be prepared to act as discussion leader if the participants expect that of you, but encourage them to proceed with you as colleagues if they have questions and ideas to maintain the discussion on their own. Do intervene by soliciting other opinions if you find that one or two persons dominate the discussion. You might also have your group join one of the other groups to continue the conversation. The questions on page 9-7 are suggested topics, but should not be used to prevent other areas germane to the workshop from being taken up.

Module 10 Suggested Reading

In addition to the suggested reading, your participants may wish to:

Design learning cycles for their own courses.

Evaluate their students' reasoning pattern and share the findings.

Establish a communications network for keeping in touch regarding science teaching and the development of reasoning.